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12.—The genus Ctenotus (Lacertilia, Scincidae) in the Northern Territory

by G. M. Storr*

Manuscript received 18 March, 1969; accepted 20 May, 1969.

Abstract

The following 26 taxa are defined and keyed out: *pantherinus ocellifer* (Boulenger), *pantherinus calx* nov., *grandis* Storr, *spaldingi* (Macleay), *robustus* nov., *saxatilis* nov., *helenae* Storr, *inornatus* (Gray), *joanae* nov., *leonhardii* (Sternfeld), *tanamiensis* nov., *hilli* nov., *essingtonii* (Gray), *decaneurus* nov., *alacer* nov., *quattuordecimlineatus* (Sternfeld), *dux* Storr, *piankai* Storr, *calurus* Storr, *colletti nasutus* Storr, *schomburgkii schomburgkii* (Peters), *schomburgkii pallescens* nov., *strauchii* (Boulenger), *taeniatus* (Mitchell), *brooksi brooksi* (Loveridge) and *brooksi aranda* nov.

Introduction

This paper is virtually a continuation of my revision (Storr 1968) of the species inhabiting the Eastern Division of Western Australia, most of which extend to the adjacent deserts of the Northern Territory. Whenever such species are represented by ample material from the Territory they are redescribed in some detail. In other cases Territory samples are too small for a local description, and the reader is referred to my earlier descriptions.

Apart from the western desert species, the Territory fauna includes at least four other elements: (1) northern taxa, few of which extend inland as far as lat. 19°S; (2) Central Highland taxa; (3) Lake Eyre Basin taxa (these are found mainly in the lower valley of the Finke); and (4) eastern desert taxa (here largely confined to the Simpson Desert and arid situations about the lower Finke). All species in these categories are described as fully as the available material allows; but some samples are inadequate for an understanding of individual, let alone geographic, variation.

In my previous paper the Eastern Division species were allotted to six species-groups; their primary function, as in this paper, was to make diagnosis easier by providing some landmarks in what otherwise might have been a bewildering array of annectant forms. The additional species occurring in the Territory can be fitted into that framework; but it was found, from the viewpoint of both diagnosis and phylogeny, that the *lesueurii* group was best restricted to those species closest to *C. lesueurii*. The residue, herein called the *leonhardii* group, is almost certainly polyphyletic: *joanae*, for example, could well prove nearer to the *lesueurii* group; *hilli* to the *schomburgkii* group; and *essingtonii*, as Boulenger implied, to the *taeniolatus* group. However, to accommodate these problematic species in the mentioned groups, the latter would have to be redefined in terms not so readily perceived as those used here (gross colour pattern and subdigital keeling).

I am grateful to the following curators for the loan of specimens: Miss J. Covacevich Queensland Museum (QM); Mr. H. G. Cogger, Australian Museum (AM); Dr. P. Stanbury, Macleay Museum (MM); Miss J. M. Dixon, National Museum of Victoria (NMV); Mr. F. J. Mitchell, South Australian Museum (SAM); Messrs. K. R. Slater and B. L. Bolton, Northern Territory Administration (NTM); Lt.-Cdr. A. Y. Norris, British Joint Services Expedition (JSE); Dr. E. R. Pianka, private collection (ERP); Dr. J. A. Peters, United States National Museum (USNM); Dr. E. Williams, Museum of Comparative Zoology (MCZ); Mr. E. N. Arnold, British Museum (Natural History); and Dr. G. Peters, Berlin Museum.

Key

1. Pattern not ocellate (indistinct ocelli may be present on side of body and tail in *grandis*); nasal weakly or not grooved ... 2
   Pattern consisting solely of bold black-and-white ocelli; nasal strongly grooved — *pantherinus* group ... 7
2. Lateral pattern (whether striped, spotted or merely flecked) longitudinally orientated ... 3
   Sides greyish with white centres of scales tending to form vertical bars; back boldly or indistinctly striped; second loreal usually high and apically angular—*grandis* group ... 8
3. Toes slightly or moderately or not compressed; subdigital lamellae smooth, callose or obtusely keeled; size small to very large ... 4
   Toes strongly compressed; subdigital lamellae with a fine sharp keel ending in a mucron or short spine; head relatively low and snout long and narrow; size small (SVL up to 55) ... 6
4. Toes slightly or moderately compressed; subdigital lamellae narrowly callose or obtusely keeled (calli moderately wide in *essingtonii* and *decaneurus*); size small to medium (SVL less than 76, except in adult *tanamiensis*) ... 5
   Toes not or slightly compressed; subdigital lamellae smooth or widely callose; first supraocular much smaller than second (first and second fused in *spaldingi*); size large (SVL up to 116)—*lesueurii* group ... 9
5. Back and sides brown, patterned with a combination of stripes, spots, dots and dashes (*essingtonii* may be virtually unspotted)—*leonhardii* group ... 13

* Western Australian Museum, Perth, Western Australia

Back and sides blackish (brown in *piankai*), patterned only with whitish stripes (an upper lateral series of pale spots in *alacer* and sometimes anteriorly in *piankai*)—*taeniolatus* group 17

6. Back and sides black, patterned solely with 8 clearcut white stripes; nasals and prefrontals usually contiguous—*colletti* group 21

Pattern including pale upper lateral spots or dark rectangular blotches—*schomburgkii* group 22

7. Subdigital lamellae sharply keeled; claws unpigmented; proximal plantars only a little larger than adjacent plantars .... *pantherinus ocellifer*

Subdigital lamellae callose (usually narrowly); claws blackish; proximal plantars greatly enlarged *pantherinus calx*

8. Back reddish, striped with dark brown (vertebral stripe well developed; others may be broken or barely discernible); tail thick, basally constricted, and marked on sides with buffy dark-edged vertical bars .... *grandis* (adult)

Back with alternating black and pale green stripes; tail slender ... *grandis* (juv.)

9. Upper labials usually 7; brow very acute and tending to conceal middle supraciliaries; ear lobules very large; second loreal 1.5 or more times as wide as high; SVL up to 116 10

Upper labials usually 8; brow obtuse or moderately acute; nuchals rarely more than 3; SVL up to 92 11

10. Supraoculars 3; nuchals seldom more than 3; dark upper lateral zone enclosing large pale blotches *spaldingi*

Supraoculars 4; nuchals seldom fewer than 4; dark upper lateral zone indistinctly marked with pale dashes or small blotches .. *robustus*

11. Prominent white dorsolateral line 12

Little or no indication of dorsolateral line *helenae*

12. Ground colour dark olive-brown; black, pale-edged vertebral stripe always present; tail usually less than 2.3 times as long as SVL . *saxatilis*

Ground colour paler; vertebral stripe usually reduced or absent in adults, rarely pale-edged; tail seldom less than 2.3 times as long as SVL .. *inornatus*

13. No dark stripes; pattern consisting solely of a white paravertebral line and dorsal and lateral series of white dots and dashes; SVL up to 92 ... *tanamiensis*

At least one dark stripe (vertebral or laterodorsal or upper lateral); SVL up to 75 14

14. Dark vertebral stripe; upper labials usually 8; nasals usually in contact 15

Little or no indication of dark vertebral stripe; upper labials usually 7 16

15. Dorsally brown; vertebral stripe dark brown, narrow or moderately wide, edged with pale brown; white midlateral stripe usually not extending forward to level of arm *leonhardii*

Dorsally olive; vertebral stripe black, very wide at midback; white midlateral stripe extending to loreal region *joanae*

16. Nasals separated or just touching; scale-rows 28 or fewer; first ear lobule largest *essingtonii*

Nasals forming median suture; scale rows 30 or more; first ear lobule small *hilli*

17. Dorsal and lateral ground colour brown with a total of 6 white stripes ... . *piankai*

Dorsal and lateral ground colour black or dark brown with a total of 10 or more white or pale brown stripes and lines 18

18. Black upper lateral zone enclosing a series of pale spots ... *alacer*

No pale spots 19

19. Pale stripes and lines 14 or more; prefrontals in contact; subdigital lamellae narrowly callose 20

White stripes 10; prefrontals separated; subdigital lamellae with moderately wide calli .... *decaneurus*

20. Pale stripes and lines 14, clearcut; ear lobules small and subacute .. *quattuordecimlineatus*

Pale stripes and lines 16 or more, often indistinct; ear lobules long and acute .... *dux*

21. Tail blue; subdigital lamellae and proximal subcaudals marked with black; second ear lobule usually largest .... .. *calurus*

Tail brown; no black marks under toes and tail; prominent midfrontal streak; first ear lobule very large .. .. *colletti nasutus*

22. Head and back not red; white dorsolateral and midlateral stripes well developed; presuboculars 2; prefrontals usually separated .. 23

Head and back red (in life); white dorsolateral and midlateral stripes absent or faint; one presubocular; prefrontals usually in contact 26

23. Back black with 4 reddish or greenish white lines; black upper lateral zone enclosing a series of pale reddish spots .... . *schomburgkii schomburgkii*

Back brown with or without pattern (a dark vertebral and modified laterodorsal stripe); upper lateral zone consisting of alternating dark and pale rectangular blotches 24

24. Nasals forming a median suture; hindleg very short (less than 40% of SVL .. .. *strauchii*

Nasals separated; hindleg more than 40% of SVL 25

25. Supraoculars 4; supraciliaries and upper labials 7 ... . *schomburgkii pallescens*

Supraoculars 5; supraciliaries and upper labials 8 . .... *taeniatus*

26. Little pattern apart from small dark squarish upper lateral blotches; hindleg seldom less than 47% of SVL ... . *brooksi brooksi*

Some development of dark dorsal stripes and of white dorsolateral and midlateral stripes; dark upper lateral blotches much higher than wide; hindleg less than 47% of SVL .. . .. *brooksi aranda*

Ctenotus pantherinus ocellifer

Lygosoma ocelliferum (Boulenger), 1896. Ann. Mag. Nat. Hist. (6) 18: 342. (For synonymy see Storr (1968: 99).)

Diagnosis. A large, stout *Ctenotus* with short, thick tail; dorsal and lateral pattern consisting solely of ocelli; nasal grooved; subdigital lamellae sharply keeled.

Distribution. Sandy deserts north to lat. 20°S. Extralimital in the Kimberley (west), North-West and Eastern Divisions of Western Australia, and northwestern South Australia.

Description. SVL (mm): 37-98; males with everted hemipenes 75-83; a gravid female 92. Length of appendages (% SVL): tail 146-195; foreleg 20-31; hindleg 32-49.

Nasals in contact. Prefrontals in contact (narrowly separated in one specimen). Supraoculars 4, first 3 (abnormally 2) in contact with frontal. Supraciliaries usually 7, occasionally 6, rarely 8. Palpebrals 9-14, anterior half of series keeled and mucronate. Second loreal 0.8-1.4 times as wide as high. Upper labials 8 (occasionally 9). Ear lobules 4-7, second or third usually largest, usually subacute in adults and obtuse in juveniles. Nuchals 2-4. Midbody scale-rows 32-37 (usually 34 or 36). Lamellae under fourth toe 20-27, each with a fine, dark keel.

Back and sides of body and tail olive brown with scattered ocelli, each consisting of a white spot or short longitudinal bar margined on each side by a short black longitudinal bar. White bars of laterocaudal ocelli tending posteriorly to form a midlateral stripe.

Remarks. The various populations are all much alike and differ from those of the Eastern Division of Western Australia only in their slightly longer appendages (a consequence no doubt of their generally lower latitude).

Material. Tanami Desert (AM 14201); 30 mi. NNW of The Granites (AM 26941); 20 mi. N of The Granites (NTM 2214); 20 mi. W of The Granites (NTM 2215); The Granites (AM 14199, 26983); 6 mi. E of The Granites (NTM 2071, 2213); 7-12 mi. SE of The Granites (ERP, 6); 40 mi. E of The Granites (NTM 2206-8); 5-10 mi. NNW of Chilla Well (ERP, 7); Corandirk (8 mi. SE of Chilla Well) (NTM 2610); Yuendumu (AM 26947-9); 20 mi. S of Tennant Creek (WAM 21521); 28 mi. NE of Barrow Creek (WAM 24348); Barrow Creek (NMV D544-5); 15 mi. SW of Barrow Creek (WAM 24364-5); Ehrenberg Range (23°17'S, 130°21'E) (JSE 400); Willie Rockhole (23°13'S, 129°45'E) (JSE 344); Kintore Range (JSE 275, 300); Davenport Hills (23°35'S, 129°19'E) (JSE 232); E of Bonython Range (23°42'S, 129°02'E) (JSE 182, 186); Hermannsburg (NTM 2362); Tempe Downs (NTM 2017); near George Gill Range (NTM 2007; Churnside Creek (Petermann Range) (JSE 143a-b); The Armstrong (JSE 88); 22 mi. E of Ayers Rock (WAM 20803); 22 mi. ENE of Curtin Springs (ERP, 4).

Ctenotus pantherinus calx subsp. nov.

Holotype. D10810 in the National Museum of Victoria, collected by A. J. Coventry and C. Tanner on 5 August 1964 at Dunmarra, Northern Territory, in 16°40'S, 133°23'E.

Diagnosis. Distinguishable from *C. p. ocellifer* by its greater size, relatively longer appendages, darker claws, unkeeled subdigital lamellae and greatly enlarged proximal plantars (in *ocellifer* they are slightly larger than adjacent plantars, which decrease gradually in size towards digits).

Distribution. Northern interior from the Roper River south to Dunmarra and the Nicholson River (Carpentaria drainage). Extralimital in Western Australia (east Kimberley).

Description. SVL (mm): 45-114. Length of appendages (% SVL): tail 192-210; foreleg 24-29; hindleg 35-46.

Nasals in contact. Prefrontals in contact. Supraoculars 4, first 3 in contact with frontal. Supraciliaries 7 (occasionally 8). Palpebrals 11-15. Second loreal 0.9-1.6 times as wide as high. Upper labials 8. Ear lobules 3-8, third or fourth usually largest, usually acute in adults and obtuse in juveniles. Nuchals 2-4. Midbody scale-rows 34-36 (usually 36). Lamellae under fourth toe 19-23, each with a narrow (rarely wide) dark-brown callus.

Coloration as in *C. p. ocellifer*.

Paratypes. Roper River Mission (NMV D10081); Roper River (QM J13000); 12 mi. N of Daly Waters (NTM 1632); Nicholson River Reserve (NTM 3860). [Western Australia: 38 mi. SSE of Wyndham (WAM 25090-1); 23 mi. SE of Kununurra (WAM 23125); 16 mi. E of Bohemia Downs (WAM 23050).]

Ctenotus grandis

Ctenotus grandis Storr, 1968, J. Roy. Soc. W. Aust. 51: 100, 24 mi. ENE of Laverton, W.A. (E. R. & H. L. Pianka).

Diagnosis. Very large, when adult, with relatively stout body and appendages; 5 dark dorsal stripes on a greenish ground (juveniles) or reddish ground (adults); sides dark with small white spots tending to form vertical bars; second loreal usually high, pentagonal, with angular apex.

Distribution. Tanami Desert. Extralimital in arid zone of Western Australia.

Description. SVL (mm) 44-74; a specimen with small hemipenes 68.5. Length of appendages (% SVL): tail 197-201; foreleg 23-30; hindleg 38-47.

Nasals in contact. Prefrontals in contact. Supraoculars 4, first 3 in contact with frontal. Supraciliaries 7 (6 in one specimen). Palpebrals 10-12. Second loreal 1.0-1.8 times as wide as high (in only one specimen more than 1.3). Upper labials 8 (9 in one specimen). Ear lobules 5-7, usually subacute in juveniles and acute in adults. Nuchals 2-4. Midbody scale-rows 28-34. Lamellae under fourth toe 24-26, each with a dark, usually narrow callus.

Remarks. As all this material is juvenile or subadult, the reader is referred to the original description for a more complete account. There is no reason for believing that the Territory populations differ significantly from those of the Eastern Division of Western Australia. The differences in relative length of appendages is almost certainly due to differences in latitude between collections.

Material: 30 mi. NNW of The Granites (AM 26945); The Granites (NTM 2081); 7 mi. SE of The Granites (ERP 11659, 11672-3); 30 mi. SW of Wauchope (WAM 24334); Yuendumu (SAM 5038).

Ctenotus spaldingi

Hinulia spaldingi Macleay, 1877, Proc. Linn. Soc. N.S.W. 2: 63. Endeavour River, Queensland (Chevert Expedition).

Lygosoma dorsale Boulenger, 1887, "Catalogue Lizards British Museum" 3: 226. Fly River, Papua (S. Macfarlane).

Diagnosis. A large member of the *lesueurii* group with well-developed pattern (including black vertebral stripe and whitish midlateral and ventrolateral stripes), 3 supraoculars, sharp brow, long ear lobules and very wide second loreal.

Distribution. South to the Victoria River basin, Larrimah and the Nicholson River (Carpentaria drainage), but evidently absent from far northwest. Extralimital in northern Queensland, Torres Strait islands and southern New Guinea.

Description. SVL (mm): 50-102; a male with everted hemipenes 93. Length of appendages (% SVL): tail 201-237; foreleg 20-26; hindleg 39-49.

Nasals narrowly separated or in short contact. Prefrontals in short to long contact. Supraoculars 3, first 2 in contact with frontal, first very long. Supraciliaries 8-12. Palpebrals 9-13. Second loreal 1.5-2.3 times as wide as high. Labials usually 7, occasionally 8. Ear lobules 3-5, long and acute in adults. Nuchals 3 (occasionally 2 or 4). Midbody scale-rows 28 or 30. Lamellae under fourth toe 18-23, each with a wide flat callus (higher proximally).

Dorsally olive green (coppery in life), more brownish on head and reddish on limbs and distal half of tail. Black vertebral stripe beginning narrowly on neck, dilating to maximum width on back and ending on base of tail; usually edged very narrowly with white. White dorsolateral line from upper postoculars to base of tail, narrowly edged above with black (this black margin, or laterodorsal stripe, may be broken into series of triangular spots). Blackish upper lateral zone enclosing series of large pale squarish blotches, partly suffused with grey and brown. Whitish midlateral stripe from lores nearly to end of tail (on which it is suffused with brown), interrupted by ear aperture and partly by thigh; anteriorly narrow and finely edged with black from lores to temples. Whitish ventrolateral stripe from groin to axilla or nearly so.

Geographic variation. The above description is based on the specimens from south of Pine Creek. The three specimens from Yirrkala are slightly different: the vertebral stripe is not so well developed; one of them has only 26 midbody scale-rows; two of them have 25 lamellae under the fourth toe; and in all three the prefrontals are narrowly separated. Perhaps this population is isolated (by the Arnhem Land plateau) from those of further south.

A large series (SAM 9343-56; NMV D8433-6) from Mornington Island (Gulf of Carpentaria, Queensland) differ from the southern populations of the Northern Territory only in their smaller size (SVL 33-90) and more numerous midbody scale-rows (28-32) and palpebrals (11-14). Their tendency for narrower second loreal and smaller nasals is shared with the nearby Nicholson River series.

Further east in Queensland, judging from the syntypes of *spaldingi* (MM 418-21), a series from Cape York (QM J1701-4) and remarks of Copland (1946), there is a reduction in dark pigment. The vertebral stripe is seldom fully developed, and the pale blotches of the upper lateral zone are confluent with the midlateral stripe. There is no pale ventrolateral stripe, and the nasals are always separated (usually widely so).

Material: Yirrkala (WAM 13516, 29789, 29791); 17 mi. SE of Pine Creek (WAM 23186-7); 22 mi. SE of Pine Creek (WAM 23185); Katherine (AM 12829); 16 mi SW of Auvergne (WAM 23140); Timber Creek (NMV D10775); Mataranka (WAM 23794); Larrimah (WAM 24122, 24125-6); 5 mi. S of Larrimah (NTM 1623-7); Nicholson River Reserve (NTM 3862, 3865, 3869).

Ctenotus robustus sp. nov.

Holotype. D4957 in National Museum of Victoria, collected by the Spencer-Gillen Expedition (1901-2) at Barrow Creek, Northern Territory, in 21°31'S, 133°53'E.

Diagnosis. A very large member of the *lesueurii* group with vertebral and subocular stripe well developed; upper labials usually 7; prefrontals in long contact. Distinguishable from *spaldingi* by reduced lateral pattern and 4 (rather than 3) supraoculars.

Distribution. South to Barrow Creek.

Description. SVL (mm): 82-116. Length of appendages (% SVL): tail 184-222; foreleg 21-26; hindleg 36-45.

Nasals narrowly separated or in short contact. Prefrontals in long contact. Supraoculars 4, first small, second very large, first three in contact with frontal. Supraciliaries 9-11. Palpebrals 10-14 (seldom less than 12). Second loreal 1.2-1.8 times as wide as high. Upper labials 7 (8 in two specimens). Ear lobules 3-7, acute or truncate, very large, second or third largest. Nuchals 4 (occasionally 3). Midbody scale-rows 28-32. Lamellae under fourth toe 18-22, each with a wide flat callus (higher proximally).

Blackish vertebral stripe with narrow creamy-white margin, beginning narrowly on neck, dilating rapidly (on midback almost as wide as a paravertebral scale) and ending fairly abruptly soon after base of tail. Creamy-white dorsolateral stripe from last supraocular to distal quarter of tail, narrower than dark margin (laterodorsal stripe) above it. Dark upper lateral zone with one or two series of more or less distinct pale dashes, sometimes clumping to form small indistinct blotches. Narrow buffy-white midlateral stripe from bottom of loreals nearly to end of tail, interrupted by ear aperture and slightly by thigh, usually broken into series of dashes from ear aperture to behind level of arm.

Geographic variation. Northern specimens (south to Port Keats) have considerably longer appendages than the Tennant Creek and Barrow Creek series.

Paratypes. East Alligator River (USNM 128756); Darwin (AM 3663, 4981); Port Keats Mission (AM 14223, 14230); Tennant Creek (NMV D40, 2912, 2918, 2922-3, 2939); Barrow Creek (NMV D548, 2925, 4958-60, 5616).

Ctenotus saxatilis sp. nov.

Holotype. R24239 in Western Australian Museum, collected by G. M. Storr and A. M. Douglas on 23 September 1964 at 10 miles east of Tennant Creek, Northern Territory, in 19°40′S, 134°20′E.

Diagnosis. A moderately large member of the *lesueurii* group with pale-edged, black vertebral stripe, and white dorsolateral stripe margined above and below with black. Distinguishable from *robustus* by absence of pale subocular stripe, narrower vertebral stripe, more numerous labials, fewer supraciliaries and nuchals, and smaller nasals and prefrontals.

Distribution. Stony hills and granite outcrops north to lat 18°S. Extralimital in far northern South Australia.

Description. SVL (mm): 41-86. Length of appendages (% SVL): tail 190-242; foreleg 20-27; hindleg 36-42.

Nasals separated (in short contact in one juvenile). Prefrontals usually in contact. Supraoculars 4, first small, second large, third narrow, first 3 in contact with frontal. Supraciliaries 6-9 (usually 7 or 8). Palpebrals 10-13 (mostly 10 or 11). Second loreal 1.3-1.8 times as wide as high. Labials usually 8 (occasionally 9, rarely 10). Ear lobules 3-7, obtuse in juveniles, acute or subacute in adults, third usually largest. Nuchals 2 or 3. Midbody scale-rows 27-32. Lamellae under fourth toe 17-24, each with a wide, flat, grey or brown callus, higher proximally.

Dorsally dark olive-brown, greyer on head, paler and browner on tail. Black, pale-edged vertebral stripe beginning narrowly on neck and extending to between base and middle of tail; on mid-back considerably narrower than a paravertebral scale. White dorsolateral line from about level of ear to base of tail, after which it becomes wider and suffused with brown; narrowly or widely margined above with black. Upper lateral zone black mottled with greyish or brownish white; pale markings coalescing, especially in juveniles to form a series of moderately large spots; represented on tail by dark-edged pale stripe. Whitish midlateral stripe, usually breaking up into spots anteriorly (i.e. from ear to level of arm), extending nearly to end of tail. Lower lateral zone dark greyish-brown, mottled paler. Greyish-white ventrolateral stripe sometimes indicated.

Paratypes. 13 mi. N of Powell Creek (WAM 24191); Helen Springs (WAM 24199); 14 mi. N of Wauchope (WAM 24297-8); 7 mi. N of Wauchope (WAM 24302-3); Barrow Creek (NMV D5055); Mt. Doreen (QMJ 13001); Alice Springs (NTM 1485; NMV D167); Ooraminna (NTM 2015); Bagots Creek (NMV D198); Hermannsburg (MCZ 35355-63); Illamurta (NMV D469); "Central Australia" (NMV D205, 2070); "Darwin" (NMV D1516).

Ctenotus helenae

Ctenotus helenae Storr, 1968, J. Roy. Soc. W. Aust. 51: 100. 24 mi. ENE of Laverton, W.A. (E. R. & H. L. Pianka).

Diagnosis. A moderately large member of the *lesueurii* group; back dark greenish-brown with little indication of pattern except for blackish vertebral stripe and mottled flanks.

Distribution. Sandy deserts north to latitude 20°S and east to Wauchope, Barrow Creek and Curtin Springs.

Description. SVL (mm): 36-92. Length of appendages (% SVL): tail 184-234; foreleg 20-29; hindleg 35-47.

Nasals separated (usually widely). Prefrontals in contact (very narrowly separated in one specimen). Supraoculars normally 4 with 3 in contact with frontal (3 with 2 on one side of one specimen), first small and second large. Supraciliaries 7 (occasionally 8, rarely 6). Palpebrals 9-13 (mostly 10 or 11). Second loreal 0.9-2.2 times as wide as high. Labials 7-9 (mostly 8). Ear lobules 3-5, obtuse in juveniles, acute or subacute in adults, second usually largest. Nuchals 2-4 (mostly 3). Midbody scale-rows 26 or 28 (rarely 30). Lamellae under fourth toe 20-26, slightly compressed, smooth or widely callose, higher proximally.

Material. Smoke Hills (31 mi. ESE of Tanami) (NTM 2775-8); 7 mi SE of Smoke Hills (NTM 2212); 26 mi. SW of Wauchope (WAM 24321-2); 6 mi. SW of Barrow Creek (WAM 24356); 15 mi. SW of Barrow Creek (WAM 24363); Yuendumu (AM 26946); Vaughan Springs (SAM 8166); Willie Rockhole (between Kintore and Ehrenberg Ranges) (JSE 342); Dead Bullock Plain, Tempe Downs (AM 26943-4); Shaw Creek (JSE 123b-c, 133); Armstrong Creek (JSE 100); Curtin Springs (JSE 47).

Ctenotus inornatus

Hinulia inornata Gray, 1845, "Catalogue lizards British Museum", p. 78. "Swan River."

Lygosoma lesueurii concolor Glauert, 1952, W. Aust. Nat. 3: 196. Marilla, Western Australia (R. A. Anderson). [not *Lygosoma (Rhodona) bipes* var *concolor* Werner.]

Diagnosis. A moderately small member of the *lesueurii* group with reduced colour pattern; white dorsolateral line always present, but narrow black vertebral stripe and lateral pattern obsolescent with age. Distinguishable from *helenae* by prominent white dorsolateral line and long tail; and from *spaldingi* by weaker brow, more numerous labials and supraciliaries, and narrower vertebral stripe (when present).

Distribution. South to the lower Victoria River, Daly Waters and the Nicholson River (Carpentaria drainage), but evidently absent from far northwest (Darwin area); Groote Eylandt. Extralimital in Western Australia (Kimberley and North-West Divisions) and Queensland (far northwest, including Mornington Island).

Description. SVL (mm): 34-87. Length of appendages (% SVL): tail 220-282; foreleg 19-32; hindleg 36-55.

Nasals usually separated (occasionally forming short suture). Prefrontals in contact (rarely separated). Supraoculars normally 4, with first 3 in contact with frontal; first small, rarely fused to second. Supraciliaries 7-11 (mostly 8). Palpebrals 9-14 (mostly 11 or 12). Second loreal 1.0-2.1 times as wide as high. Labials 8 (rarely 7 or 9). Ear lobules 3-7, obtuse in juveniles, acute or truncate in adults, first usually smallest, second or third usually largest. Nuchals usually 3, occasionally 2, rarely 4. Midbody scale-rows 27-34. Lamellae under fourth toe 18-26, slightly compressed, each with a flat wide callus (higher proximally).

Dorsally brown or olive brown, becoming paler and more reddish on tail and limbs. Occasionally a narrow black vertebral stripe from neck to base of tail, not or indistinctly pale-edged; usually reduced to a line on neck or fore-back; often completely absent. Narrow white dorsolateral stripe from brow or neck to tail (on which it is wider and brownish), narrowly and sometimes indistinctly margined above with blackish brown (paler on tail). Upper lateral zone dark brown, dotted or flecked with black and/or white; sometimes, especially in juveniles, bearing a series of white spots. Pale midlateral stripe variably developed; usually indistinct, greyish white and not extending forward beyond level of arm; sometimes (especially in juveniles) clearcut, white and extending forward to loreals as a narrow subocular stripe. Lower lateral zone greyish brown, with or without whitish or black flecks.

Material. Yirrkala (AM 12388-98, 12433-4, 26950-69; SAM 2860; WAM 13524, 29788, 29790, 29793-813; USNM 128577-84, 128586, 128593, 128596-7, 128599, 128601, 128608, 128619); Oenpelli (NMV D5163-4, 5167; USNM 128757); Mt Bundey (SAM 5949); Manton Dam (SAM 8931); Daly River (NTM 1601); Katherine (WAM 13987, 14003, 14032-3, 21908-16); 21 mi. NW of Newry (WAM 23129); Timber Creek (NMV D10766); 20 mi. N of Larrimah (WAM 23800-1); 10 mi. N of Larrimah (WAM 23808-9); 5 mi. N of Larrimah (NTM 1614-20); Larrimah (AM 12830; W.A.M. 24123-4, 24127-8); 5 mi. S of Larrimah (NTM 1621-2); 14 mi. N of Daly Waters (NTM 1608-12, 1631); Groote Eylandt (AM 9716-8, 10198, 26984; USNM 128389-90, 128392-401; NTM 1074); Borroloola (NMV D5090, 5092, 5115-8); Juster Creek, Nicholson River Reserve (NTM 3861, 3863-4, 3866-8).

Ctenotus joanae sp. nov.

Holotype. D5787 in National Museum of Victoria, collected by G. F. Hill on 15 July 1911 at Newcastle Waters, Northern Territory, in 17°23'S, 133°25'E.

Diagnosis. A short-legged, aberrant member of the *leonhardii* group with black vertebral and white midlateral stripes well developed; first ear lobule much the largest.

Distribution. Known only from one specimen from northern interior.

Description. SVL (mm): 47. Length of appendages (% SVL): foreleg 25; hindleg 41.

Nasals in moderately long contact. Prefrontals separated moderately widely. Supraoculars 4, first 3 in contact with wrontal. Supraciliaries 7. Palpebrals 8 or 9. Second loreal 1.3-1.5 times as wide as high. Upper labials 8. Ear lobules 2 or 3, obtuse. Nuchals 5. Midbody scale-rows 26. Lamellae under fourth toe 19 or 20, each with a narrow dark callus.

Dorsally pale olive. Prominent black vertebral stripe from neck to tail, very wide on midback; only slight indication of extremely narrow pale edge. Narrow white dorsolateral stripe from brow to tail, widely margined above with black. Upper lateral zone olive brown with a series of small indistinct pale spots. Whitish midlateral stripe from bottom of second loreal nearly to end of tail, looping sharply above ear, sending branch down to arm, and almost completely interrupted by thigh. Pale olive-brown lower lateral streak from below and behind ear to tail, interrupted at arm (by branch of midlateral stripe) and hindleg. Some indication of whitish ventrolateral stripe.

Remarks. Named after Miss Joan M. Dixon, Curator of Vertebrates, National Museum of Victoria, in appreciation of the loan of the splendid collection in her care.

Ctenotus leonhardii

Lygosoma (Hinulia) leonhardii Sternfeld, 1919, Senckenbergiana 1: 79. Hermannsburg, Northern Territory (M von Leonhardi).

Diagnosis. A moderately large member of the *leonhardii* group; dark, pale-edged vertebral stripe always present; white midlateral stripe discernible posteriorly; upper lateral zone with longitudinal series of pale dots; nasals usually in contact; prefrontals usually separated.

Distribution. North to the Tanami Desert, Morphett Creek and Lake Nash. Extralimital in arid zone of Western Australia, Queensland and South Australia.

Description. SVL (mm): 33-75. Length of appendages (% SVL): tail 167-238; foreleg 21-31; hindleg 38-52.

Nasals usually in contact (occasionally narrowly separated, never widely). Prefrontals usually separated narrowly (occasionally separated moderately widely or in short contact). Supraoculars 4, first 3 in contact with frontal. Supraciliaries 6-8 (usually 7). Palpebrals 8-13. Second loreal 1.0-1.9 times as wide as high. Labials 8 (occasionally 9, very rarely 7 or 10). Ear lobules 2-6; obtuse in juveniles, usually acute in adults, second or third usually largest. Nuchals 2-5 (mostly 4). Midbody scale-rows 26-33 (mostly 28 or 30). Lamellae under fourth toe 21-28, each with narrow brown callus or obtuse keel.

Dorsally brown (paler in north and desert regions, darker in southern highlands). Dark brown vertebral stripe (sometimes narrow or indistinct in north), narrowly edged with pale brown. Whitish dorsolateral line, narrowly or widely margined above with dark brown. Dark-brown upper lateral zone with 1-3 longitudinal

series of pale dots. White midlateral stripe usually well developed posteriorly, becoming broken towards arm.

Material. 55 mi E of The Granites (NTM 2082, 2210); 7 mi. S of Banka Banka (WAM 24215); Lake Nash (SAM 7727); Tennant Creek and vicinity (NMV D37, 80, 2910; WAM 21462-6); 20 mi. S of Tennant Creek (ERP 9854); 19 mi. NE of Barrow Creek (WAM 24351); Barrow Creek (NMV D547, 4961-4, 5053, 5055-7); Aileron (WAM 24421); Kintore Range (JSE 241); Haasts Bluff (NMV D7749-52); Mt Liebig (SAM 6104-5); Mt Conway (AM 14190-2, 14194, 26971-82); Alice Springs and vicinity (NMV D165; NTM 1870-1, 2036-7); Arltunga (NTM 2854); Owen Springs (WAM 20851); Hermannsburg (MCZ 33529—paratype); Illamurta (NMV D451, 454, 458, 460, 462, 466, 468, 470-1, 474); Curtin Springs (WAM 20810-1); Mt Olga (JSE 77-8); Shaw Creek (JSE 123a); Kulgera (AM 14188); Charlotte Waters (NMV D2708); "Central Australia" (NMV D206, 271, 274, 275).

Ctenotus tanamiensis sp. nov.

Holotype. 2079 in the collection of the Animal Industry Branch, Northern Territory Administration, collected by K. R. Slater, D. R. Stephens and D. A. Lindner on 9 September 1964 at The Granites, Northern Territory, in 20°34′S, 130°22′E.

Diagnosis. A very large member of the *leonhardii* group with colour pattern consisting mainly of longitudinal series of white dots and dashes.

Distribution. Tanami Desert.

Description. SVL (mm): 49-91. Length of appendages (% SVL): tail 204-233; foreleg 23-29; hindleg 41-50.

Nasals in contact (separated in one specimen). Prefrontals usually separated, occasionally in short contact. Supraoculars 4, first 3 in contact with frontal (5 with 4 on one side of one specimen; first longitudinally divided on each side of another). Supraciliaries 6-9. Palpebrals 11-13. Second loreal 1.3-2.1 times as wide as high. Ear lobules 4-7; obtuse in juveniles, acute or subacute in adults; second or third largest. Nuchals 2 or 3 (mostly 2). Midbody scale-rows 29-32 (mostly 30). Subdigital lamellae 24-30, moderately compressed, each with a narrow dark callus or obtuse keel.

Back and upper half of flanks dark reddish-brown. Head, tail, lips and lower half of flanks pale reddish-brown. Whitish paravertebral line from nape to base of tail, not extending anteriorly or posteriorly quite so far as adjacent vertebral stripe (i.e. dorsal ground colour). Remainder of back and flanks with 7 or 8 series of small whitish dots or dashes: those of first series (laterodorsal) relatively large, circular and suffused with brown; second series (dorsolateral) white and tending to be short longitudinally oriented dashes rather than dots; 2 or 3 series of upper lateral dots (on dark ground), very small and aligned vertically as much as longitudinally; midlateral and lower lateral dots (on pinkish-brown ground) larger and increasingly irregular in alignment. Dark-brown laterodorsal and upper lateral stripes on tail, first extending to about middle of tail, second nearly to end. Narrow white streak curving round bottom of orbit. Lips vertically barred with white and brown. Lower surface whitish, suffused with buff under tail.

Paratypes. The Granites (NTM 2080, 2218-21); 7 mi. SE of The Granites (ERP 11639, 11671); 7 mi. NW of Thompsons Rockhole (NTM 2203); 10 mi. SE of Renahans Well (ERP 11612).

Ctenotus hilli sp. nov.

Holotype. R23569 in Western Australian Museum, collected by G. M. Storr and A. M. Douglas on 18 September 1964 at Darwin, Northern Territory, in 12°26′S, 130°55′E.

Diagnosis. A very small, aberrant member of the *leonhardii* group with little or no dorsal pattern. Similar in coloration to *essingtonii* but differing markedly in scutation: larger nasals, smaller prefrontals, shorter frontal, smaller and more numerous ear lobules and more numerous midbody scale-rows.

Distribution. Except for a specimen from the "upper Roper River" only known from far northwest (Darwin and Bathurst Island).

Description. SVL (mm): 27-49. Length of appendages (% SVL): tail 166-230, foreleg 25-32, hindleg 47-53.

Nasals forming median suture (usually moderately long). Prefrontals widely separated. Supraoculars 4, first 3 in contact with frontal. Supraciliaries 7 or 8. Palpebrals 9-12. Second loreal 1.1-1.6 times as wide as high. Labials 7 (occasionally 8). Ear lobules 4-6; small; obtuse in juveniles, usually subacute in adults; third usually largest (never first). Nuchals 3-5 (usually 4). Midbody scale-rows 30-34. Lamellae under fourth toe 22-28, compressed, each bearing an obtuse dark-brown keel.

Dorsally brown, usually without pattern; occasionally a dark vertebral line or narrow stripe. White dorsolateral line from last supraocular to tail, broadly margined above with blackish brown. Upper lateral zone blackish brown with a series of small, white longitudinally elongate spots; represented on tail by prominent black stripe nearly to tip. White midlateral stripe from thigh to level of arm, thence forward as a series of spots or dashes, and finally as an indistinct subocular stripe. Lower lateral zone usually unpatterned; occasionally brown with a series of white spots.

Remarks. Named after the distinguished zoologist, Gerald F. Hill, who collected most of the type series.

Paratypes. Bathurst Island (NMV D1652); Darwin (QM J2613-8; NMV D5525, 12371-2); upper Roper River (NMV D5140).

Ctenotus essingtonii

Tiliqua essingtonii Gray, 1842, "Zoological miscellany", p. 51. Port Essington, Northern Territory (J. Gilbert).

Diagnosis. A moderately small, aberrant member of the *leonhardii* group with subdigital calli wider than usual; little or no indication of vertebral stripe; nasals and prefrontals usually separated; upper labials usually 7; ear lobules usually 2 or 3, first largest.

Distribution. North coast from Darwin to Yirrkala, inland to Mt Bundey and Oenpelli; Bathurst and Melville Islands; Groote Eylandt.

Description. SVL (mm): 28-64. Length of appendages (% SVL): tail 189-250; foreleg 21-29; hindleg 37-51.

Nasals separated (occasionally touching). Prefrontals separated (rarely touching). Supraoculars 4, first small, second large, third narrow, first 3 in contact with frontal. Supraciliaries 7-10. Palpebrals 8-13. Second loreal 1.0-1.7 times as wide as high. Labials 7 (occasionally 8). Ear lobules 2 or 3 (rarely 4 or 5), obtuse or subacute. Nuchals 3-6 (usually 4). Midbody scale-rows 24-28. Lamellae under fourth toe 20-26, slightly compressed, each with a moderately wide dark-brown callus.

Dorsally olive brown (coppery in life), darker on head, paler and more reddish on tail and limbs. Vertebral stripe absent or reduced to blackish-brown line on neck. White dorsolateral line from last supraocular to base of tail (on which it gradually merges with ground colour), margined above with blackish brown. Upper lateral zone blackish brown, sometimes dotted anteriorly with pale reddish-brown: represented on tail by series of dark transverse marks or small spots. Narrow white midlateral stripe from behind ear to hindleg. Lower lateral zone pale greyish-brown, spotted anteriorly with white. Limbs variegated with dark brown.

Geographic variation. The above colour description applies especially to western material. Eastern specimens (Yirrkala and Groote Eylandt), as Mitchell (1955: 395) observed, have pale spots throughout the upper lateral zone. Their dorsal colour (in alcohol) is olive grey rather than brown. Other slight differences are more numerous scale-rows (never 24) and ear lobules (never 2). The Groote Eylandt specimens differ from Yirrkala specimens in the faintness or even absence of lower lateral stripe.

Two specimens from Borroloola (NMV D5114, 5603) agree generally with *essingtonii* but probably belong to another race. They have a pale-edged dark vertebral stripe, no upper lateral spots and only 19-21 subdigital lamellae.

A specimen from Oenpelli (USNM 128758) diverges still more from typical *essingtonii*. It has a black white-edged vertebral stripe; a full series of small upper lateral spots (pale brown and longitudinally elongate); 24 scale-rows; widely separated nasals; and 5 small ear lobules, the third of which is largest.

Material. Port Essington (holotype); Darwin and vicinity (QM J2623; USNM 128251-6; NMV D1640, 5156-7; SAM 3592, 9360; NTM 4057; WAM 23449, 23501, 23518-23, 23541-59, 23589); Mt Bundey (SAM 5950-1); Oenpelli (NMV D5165-6); Yirrkala (USNM 128602-10); Bathurst Island (NMV D1654); Melville Island (NMV D5241, 5244); Groote Eylandt (NMV D9196-7; USNM 128402-7).

Ctenotus decaneurus sp. nov.

Holotype. R23130 in Western Australian Museum, collected by G. M. Storr and A. M. Douglas on 9 September 1964 at 21 mi. WNW of Newry, Northern Territory, in 15°59'S, 129°00'E.

Diagnosis. A member of the *taeniolatus* group with subdigital lamellae wider than usual and snout long and low (as in *colletti* group); back and sides blackish with a total of 10 white lines and stripes.

Distribution. Only known from two northern localities.

Description (of holotype). SVL (mm): 37. Length of appendages (% SVL): tail 187, foreleg 29; hindleg 48.

Nasals in short contact. Prefrontals widely separated. Supraoculars 4, first 3 in contact with frontal. Supraciliaries 8. Second loreal 1.2 times as wide as high. Labials 8. Ear lobules 4 or 6, subacute. Nuchals 4. Midbody scale rows 26. Lamellae under fourth toe 20, each with a moderately wide, brown callus.

Head greyish brown; back and sides blackish brown; upper surface of limbs reddish brown. White paravertebral line from nape to tail (on which it becomes pale reddish-brown). White dorsal line beginning about centre of parietal and finishing abruptly just behind level of hindleg. White dorsolateral line from last supraocular to proximal third of tail (on which it is suffused with reddish brown). White midlateral stripe from second loreal to at least middle of tail, looping above ear aperture and interrupted slightly by thigh. White ventrolateral stripe from behind bottom of ear aperture to groin, partly interrupted by arm. Limbs longitudinally streaked with dark brown. Under surface white.

Paratype. AM 13005 from "Darwin area". This specimen is poorly preserved but seems to agree with the holotype in most respects (including size, length of limbs, colour pattern and disposition of upper head-shields). It differs in having fewer labials (7), fewer nuchals (3), wider second loreal (1.9) and apparently fewer ear lobules (one of which is much larger than others and very obtuse).

Ctenotus alacer sp. nov.

Holotype. R20903 in the Western Australian Museum, collected by G. M. Storr and K. R. Slater on 18 July 1963 at Alice Springs, Northern Territory, in 23°38'S, 133°52'E.

Diagnosis. A medium-sized member of the *taeniolatus* group with black upper lateral zone bearing a series of pale spots; nasals and prefrontals usually separated.

Distribution. Stony hills of Central Australia, from Barrow Creek south to the Macdonnell Ranges.

Description. SVL (mm): 32-62. Length of appendages (% SVL): tail 204-242; foreleg 25-31; hindleg 47-55.

Nasals narrowly separated (occasionally in very short contact). Prefrontals separated (rarely in very short contact). Supraoculars 4, first three in contact with frontal. Supraciliaries 7 (occasionally 6). Palpebrals 9-12. Second loreal 1.2-2.2 times as wide as high. Labials 8 (rarely 9). Ear lobules 5, occasionally 4; second (occasionally third) largest; subacute or acute in adults, obtuse in juveniles. Nuchals 3 or 4 (occasionally 2 or 5). Midbody scale-rows 28-32. Lamellae under fourth toe 20-28 (only one specimen with fewer than 24), each with a narrow brown callus or obtuse keel.

Ground colour of head olive brown, paler on snout; and of tail and upper surface of limbs pale reddish brown. Back black with a total of 6 white lines tinged with green, yellow or brown; paravertebral from nape to base of tail, its anterior extension reaching irregularly to side of frontal; dorsal from supraoculars to base of tail; dorsolateral from supraciliaries to base of tail. Black upper lateral stripe from orbit to base of tail, enclosing a series of whitish longitudinally elongate spots tending anteriorly to coalesce into a stripe (which, bending down behind ear, joins midlateral stripe); represented on tail by pale brown stripe, very narrowly edged with dark brown. White midlateral stripe from lores to groin (whence, becoming brownish, it continues down leg), interrupted by ear aperture and tending to be discontinuous between ear and arm. White ventrolateral stripe from behind and below ear to arm (whence it continues down foreleg); sometimes represented between axilla and groin by a series of coalescing spots. Upper surface of limbs longitudinally streaked with reddish brown. Under surface white.

Paratypes. Barrow Creek (NMV D4965, 5048); Alice Springs (NTM 3945, 4105; NMV D202-3; WAM 20904); Mt Gillen (AM 12016); Mt Conway (AM 14193); Macdonnell Range (SAM 5588); "Central Australia" (NMV D208, 277).

Ctenotus quattuordecimlineatus

Lygosoma (Hinulia) quattuordecimlineatum Sternfeld, 1919. Senckenbergiana 1: 80. Hermannsburg, Northern Territory (M. von Leonhardi).

Diagnosis. A medium-sized member of the *taeniolatus* group; back and sides dark with a total of 14 pale stripes and lines. Further distinguishable from *alacer* by contiguous nasals and prefrontals and by having 2 white lines (instead of a series of spots) between white dorsolateral and midlateral stripes; and from *dux* by clear-cut lateral pattern, more or less distinct anterior extension of pale outer dorsal line along edge of frontonasal and frontal, and tendency for dark laterodorsal stripe on tail to be aligned with dark inner (not outer) dorsal stripe of body.

Distribution. Sandy deserts north to lat. 23°S. Extralimital in Western Australia (Eastern Division) and South Australia (Great Victoria Desert).

Description. SVL (mm): 35-62. Length of appendages (% SVL): tail 211-240; foreleg 21-32; hindleg 41-49.

Nasals in contact. Prefrontals in contact. Supraoculars 4, first 3 in contact with frontal. Supraciliaries 7 (rarely 5, 6 or 8). Palpebrals 10-13. Second loreal 1.2-1.6 times as wide as high. Labials 8 (9 in one specimen). Ear lobules 2-6, first or second largest, obtuse in juveniles, subacute in adults. Nuchals 0-4 (mostly 2 or 3). Midbody scale-rows 26-30. Lamellae under fourth toe 18-29, each with a narrow dark callus.

Material. 22 mi. E of Sandy Blight Junction (23°13'S, 129°54'E) (ERP 11573); Hermannsburg (MCZ 35380; NMV D281); Norman Gully, Palm Valley Reserve (NTM 3372); Armstrong Creek (JSE 109); 58 mi. W of Mt Olga (WAM 20781); Curtin Springs (JSE 33, 38, 47a); 16 mi. SW of Angas Downs (ERP 9910); Horseshoe Bend (ERP 9900-1).

Ctenotus dux

Ctenotus dux Storr, 1968, J. Roy. Soc. W. Aust. 51: 104. 5 mi NE of Dunges Table Hill, W.A. (E. R. & H. L. Pianka).

Diagnosis. A moderately large member of the *taeniolatus* group; back and sides dark with a total of 16 or 18 pale lines. Further distinguishable from *quattuordecimlineatus* by very long and acute ear lobules.

Distribution. Sandy deserts of southwest.

Description. SVL (mm): 45-67. Length of appendages (% SVL): tail 187-234; foreleg 24-28; hindleg 43-49.

Nasals in contact or narrowly separated. Prefrontals in contact. Supraoculars 4, first 3 in contact with frontal. Supraciliaries 7 (8 in one specimen). Palpebrals 10-12. Second loreal 1.3-2.0 times as wide as high. Labials 8. Ear lobules 3-6. Nuchals 2-4. Midbody scale-rows 28 or 30. Lamellae under fourth toe, 23-28, each with a dark narrow callus.

Remarks. Only the specimen from Angas Downs agrees well with topotypical *dux* in coloration. Though the remaining specimens are badly darkened by formalin, it is evident that their pale lateral lines become increasingly indistinct inferiorly—a characteristic of *C. ariadnae* (Storr 1968) of Western Australia. All specimens share another *ariadnae* characteristic: the extremely long and narrow ear lobules.

Material. Kintore Range (JSE 271); Armstrong Creek (JSE); Curtin Springs (JSE 20, 25, 47b); 16 mi. SW of Angas Downs (ERP 9905).

Ctenotus piankai

Ctenotus piankai Storr, 1968, J. Roy. Soc. W. Aust 51: 106. 24 mi. ENE of Laverton, W.A. (E. R. & H. L. Pianka).

Diagnosis. A small member of the *taeniolatus group;* brown with a total of 6 white stripes or lines (a paravertebral, dorsolateral and midlateral on each side).

Distribution. Probably north to lat. 17°S. Extralimital in Western Australia (arid zone and south Kimberley) and far northwestern Queensland (Nicholson River).

Description (including 2 extralimital specimens). SVL (mm): 31-52. Length of appendages (% SVL): tail 187-260; foreleg 25-30; hindleg 42-50.

Nasals in contact. Prefrontals in contact or narrowly separated. Supraoculars 4, first 3 in contact with frontal. Supraciliaries 6 (occasionally 7 or 8). Palpebrals 8-10. Second loreal 0.9-1.7 times as wide as high. Upper labials 8 (7 in one specimen). Ear lobules 2-5, obtuse in juveniles, acute in adults. Nuchals 3-5 (mostly 4). Midbody scale-rows 24-26 (mostly 24). Lamellae under fourth toe 20-24, each with a narrow callus.

Material. 7 mi. SE of The Granites (ERP 11645); 10 mi. ENE of Thompsons Rockhole (NTM 2144); 28 mi. SE of The Granites (NTM 2609); Shaw Creek (JSE 133); Curtin Springs (JSE 47). [Western Australia: White Mountain, Ord River Station (WAM 27131). Queensland: Doomadgee Mission (SAM 5387).]

Ctenotus calurus

Ctenotus calurus Storr, 1968, J. Roy. Soc. W. Aust. 51: 107. 24 mi. ENE of Laverton, W.A. (E. R. & H. L. Pianka).

Diagnosis. A small member of the *colletti* group; tail blue above and white below (proximal subcaudals marked with black, especially ventrolaterally); back and sides black with a total of 8 white stripes or lines (a paravertebral, dorsal, dorsolateral and midlateral on each side); black spots under toes.

Distribution. Sandy deserts of the southwest.

Description. SVL (mm): 43-45. Length of appendages (% SVL): tail 202; foreleg 26, hindleg 46-47. Nasals in contact. Prefrontals in contact. Supraciliaries 7 or 8. Palpebrals 10-13. Labials 7 or 8. Ear lobules 2 or 3. Nuchals 2 or 3. Midbody scale-rows 24 or 26. Lamellae under fourth toe 22-25, each with a weak keel.

Material. 7 mi NW of Mt Chapple Bore (23°12'S, 132°50'E) (ERP 9870); 16 mi. SW of Angas Downs (ERP 9765).

Ctenotus colletti nasutus

Ctenotus colletti nasutus Storr, 1968, J. Roy. Soc. W. Aust. 51: 108. 5 mi NE of Dunges Table Hill, W.A. (E. R. & H. L. Pianka).

Diagnosis. A small member of the *colletti* group with snout long and narrow and upper ear lobule greatly enlarged; back and sides blackish brown with a total of 8 whitish stripes or lines (a paravertebral, dorsal, dorsolateral and midlateral). Further distinguishable from *calurus* by more strongly developed midfrontal streak and by lack of blue on tail and of black markings under tail and toes.

Distribution. Sandy deserts immediately south and east of the Kintore Range. Extralimital in the Great Victoria Desert of Western Australia.

Description and *Material.* See Storr (*supra cit.*)

Ctenotus schomburgkii schomburgkii

Lygosoma schomburgkii Peters, 1863, Mber. Akad. Wiss. Berlin 1863: 231. "Buchsfeld, near Adelaide, South Australia."

Diagnosis. A member of the *schomburgkii* group with nasals and prefrontals usually separated; back black with 4 reddish or greenish-white lines (paravertebral continuous, outer dorsal tending to break up into spots); black upper lateral zone enclosing a series of pale red spots; white dorsolateral and midlateral lines well developed.

Distribution. North to The Granites and Tennant Creek. Extralimital in Western Australia, northern South Australia and western New South Wales.

Description. SVL (mm): 26-51. Length of appendages (% SVL): tail 160-212; foreleg 25-31; hindleg 44-52.

Nasals narrowly separated (occasionally in very short contact). Prefrontals separated (occasionally in very short contact). Supraoculars 4, with first 3 in contact with frontal (rarely 5 with 4). Supraciliaries 6-8 (mostly 7, rarely 8). Palpebrals 8-11 (one specimen with 13). Second loreal 1.4-2.5 times as wide as high. Labials 7 (occasionally 8). Ear lobules 2-4 (rarely 5), usually obtuse, first or second usually much larger than others. Nuchals 2-6 (mostly 4). Midbody scale-rows 25-30 (mostly 26, rarely 30). Lamellae under fourth toe 19-24 (one specimen with 27), each with a fine, dark mucronate keel.

Material. 30 mi. NNW of The Granites (AM 26942); 7 mi. SE of The Granites (ERP 11644, 11647); Tennant Creek (NMV D67); Barrow Creek (NMV D4966, 5046-7, 5049-52, 5054, 5058); 17 mi. S of Teatree (WAM 24407); Ailcron (NTM 1461; WAM 24422); Kintore Range (JSE 272); Alice Springs (NMV D204); Bagots Creek (NMV D279); Palm Valley (NTM 3376); Illamurta (NMV D452-3, 456, 459, 461, 465, 472); "Central Australia" (NMV D2332).

Ctenotus schomburgkii pallescens subsp. nov.

Holotype. R24218 in Western Australian Museum, collected by G. M. Storr and A. M. Douglas on 23 September 1964 at Morphett Creek, 7 mi. S of Banka Banka, Northern Territory, in 18°53'S, 134°05'E.

Diagnosis. Differing from *C. s. schomburgkii* in pale brown back (almost patternless in adults), more midbody scale-rows, fewer subdigital lamellae and narrower second loreal.

Distribution. Northern interior from Elliott south nearly to Tennant Creek.

Description. SVL (mm): 34-44. Length of appendages (% SVL): tail 160-199; foreleg 26-28; hindleg 46-52.

Nasals narrowly separated. Prefrontals separated. Supraoculars 4, first 3 in contact with frontal. Supraciliaries 7. Palpebrals 9 or 10. Second loreal 1.4-1.7 times as wide as high. Labials 7. Ear lobules 2-5, obtuse, first usually largest. Nuchals 3-5. Midbody scale rows 28-30. Subdigital lamellae 18-22, each with a dark fine keel terminating in a mucron or short spine.

Dorsally pale greyish-brown with or without a rufous suffusion over back, tail and upper surface of limbs. In juveniles and subadults an indistinct blackish vertebral line from nape to tail (base only or whole length) and a dark laterodorsal streak from nape to base of tail, enclosing a series of pale transversely elongate spots. Pale dorsolateral line from first supraciliary to proximal part of tail. Dark upper lateral zone enclosing pale reddish-brown or greyish-white vertically narrow bars; represented anteriorly by dark loreal streak, and on tail by dark dorsolateral line. Whitish midlateral line from upper lip to hindleg, bending sharply up and down as it passes round top of ear aperture. From ear to groin a ventrolateral series of alternating grey and whitish spots or squarish blotches. Upper surface of limbs reticulated with dark brown.

Paratypes. Elliott (WAM 24188): Morphett Creek (WAM 24216): Phillip Creek, 25 mi. N of Tennant Creek (WAM 21470).

Ctenotus strauchii

Lygosoma strauchii Boulenger, 1887, "Catalogue—lizards—British Museum", 2nd edition, 3: 229 Gayndah, Queensland.

Diagnosis. A moderately large member of the *schomburgkii* group with extremely short limbs; nasals in contact; prefrontals separated; little or no dorsal pattern.

Distribution. Far south: valley of the Finke River, north and west to Tempe Downs. Extralimital in interior of eastern Australia.

Description (including 2 extralimital specimens). SVL (mm): 47-55. Length of appendages (% SVL): tail 160; foreleg 21-24; hindleg 33-38.

Nasals in moderately long contact. Prefrontals moderately to widely separated. Supraoculars 4, first 3 in contact with frontal. Supraciliaries 6 or 7 (mostly 7). Palpebrals 9-11. Second loreal 1.4-1.6 times as wide as high. Labials 8 (9 in one specimen). Ear lobules 2 or 3, obtuse. Nuchals 2-4. Midbody scale-rows 26-30. Subdigital lamellae 17-20, each with a fine dark mucronate keel.

Dorsally reddish brown with or without dark variegations (the most consistent being a laterodorsal series of very small blotches). Little or no indication of pale dorsolateral line. Upper lateral series of black oblong blotches, higher than wide. Narrow white midlateral stripe from below eye to base of tail, bending above ear aperture and interrupted by thigh; bordered below by narrow pale-grey stripe.

Geographic variation. The Birdsville specimen is a little different from the others. It is dorsally olive-grey with more pronounced blackish variegations, and there is no pattern below the upper lateral blotches. It alone has 9 labilas and 30 midbody scale-rows.

Remarks. It is not known whether these populations from the Lake Eyre basin are continuous with those of eastern Queensland and New South Wales. At any rate there are few if any differences. Western specimens seem to have on average slightly more labials and fewer nuchals, prefrontals not quite so widely separated, and ear lobules a little fewer and more disparate in size.

Material. Tempe Downs (NMV D280); Charlotte Waters (NMV D946). [South Australia: Lambinna (NTM 1548). Queensland: Birdsville (QM J9743).]

Ctenotus taeniatus

Lygosma (Sphenomorphus) taeniata Mitchell, 1940, Rec. S. Aust. Mus. 9: 180. Andamooka Ranges, S.A. (F. J. Mitchell).

Diagnosis. A member of the *schomburgkii* group distinguishable from all others by 5 supraoculars and 8 supraciliaries. Further distinguishable from *strauchii* by longer limbs and separated nasals, and from *brooksi* by 2 presuboculars and brownish (rather than bright red) back.

Distribution. Only known from Alice Springs and the type locality.

Description. SVL (mm): 40-41. Length of appendages (% SVL): tail 180; foreleg 25-27; hindleg 44-47.

Nasals narrowly to moderately separated. Prefrontals in contact or very narrowly separated. Supraoculars 5, first 4 in contact with frontal. Supraciliaries 8. Palpebrals 9. Second loreal 1.3-2.2 times as wide as high. Labials 8. Ear lobules 4 or 5, obtuse or subacute, second largest. Nuchals 4. Midbody scale-rows 26 or 28. Lamellae under fourth toe 20-21, each with a fine dark keel.

Dorsally reddish brown with a dark vertebral line from nape to base of tail and obscure laterodorsal variegations. Whitish dorsolateral line from temple to base of tail, very narrowly edged above and below with blackish brown. An upper lateral series of blackish-brown rectangular blotches, higher than wide. Whitish midlateral line from snout to tail, interrupted by ear aperture and hindleg. Lower lateral zone like upper but paler and narrower.

Material. Alice Springs (NMV D166). [South Australia: holotype.]

Ctenotus brooksi brooksi

Sphenomorphus leae brooksi Loveridge, 1933, Occ. Pap. Boston Soc. Nat. Hist. 8: 95. "Perth, W.A."

Diagnosis. A member of the *schomburgkii* group with head and tail red in life (fading in alcohol to pale green); little or no indication of stripes; upper lateral series of small squarish dark blotches; prefrontals in contact; only one presubocular.

Distribution. Sandy deserts of the southwest, north to lat. 23°S and east to Mt Conner. Extralimital in Western Australia (Eastern Division) and western South Australia (Great Victoria Desert).

Description. SVL (mm): 27-48.5. Length of appendages (% SVL): 160-206; foreleg 24-32; hindleg 44-55.

Nasals separated (occasionally in short contact). Prefrontals in contact. Supraoculars 4 with first 3 in contact with frontal (5 with 4 in one specimen). Supraciliaries 6 or 7 (mostly 7). Palpebrals 8-11 (12 in one specimen). Second loreal 1.3-2.3

times as wide as high. Upper labials 7 or 8. Ear lobules 3 (rarely 2 or 4), obtuse in juveniles, usually subacute in adults, second usually largest. Nuchals 3 or 4 (occasional specimens have none; these are excluded from mean given in Table I). Midbody scale-rows 24-26. Lamellae under fourth toe 22-28, each with a fine dark mucronate keel.

Material. Ehrenberg Range (23 17′S, 130 21′E) (JSE 363, 379, 390, 401, 406); 22mi. E of Sandy Blight Junction (23 13′S, 129°54′E) (ERP 11555-9, 11561-3, 11565-6, 11569, 11574, 11576-7, 11592, 11602); Willie Rockhole (23°16′S, 129 45′E) JSE 333a-d, 341a-b, 350a-e, 362a-e); SE of Bonython Range (JSE 202a-e; ERP 11547); Armstrong Creek (JSE a-b); Curtin Springs (JSE 19); Mt Conner (JSE 65A).

Ctenotus brooksi aranda subsp. nov.

Holotype. 2931 in the collection of the Animal Industry Branch, Northern Territory Administration, collected by D. A. Lindner on 6 June 1965 at Ringwood, Northern Territory, in 24 21′S, 135 05′E.

Diagnosis. Differing from *C. b. brooksi* in greater size, shorter appendages, fewer subdigital lamellae and stronger pattern (including indication of white midlateral and dorsolateral lines and better development of dark dorsal lines and upper lateral blotches, which are much higher than wide).

Distribution. Simpson Desert. Extralimital in adjacent deserts of far northern South Australia and southwestern Queensland.

Description (including extralimital specimens). SVL (mm) 28-53. Length of appendages (% SVL): tail 159; foreleg 24-28; hindleg 41-46.

Nasals narrowly separated or in short contact. Prefrontals in contact. Supraoculars 4, first 3 in contact with frontal. Supraciliaries 6 or 7. Palpebrals 9-11. Second loreal 1.7-2.4 times as wide as high. Labials 7 or 8 (mostly 8). Ear lobules 2-4 (mostly 3), obtuse in juveniles, usually subacute in adults, first or second largest. Nuchals 3-5 (two specimens with none are omitted from mean in Table I). Midbody scale-rows 26. Lamellae under fourth toe 19-25, each with a fine dark mucronate keel.

Remarks. This is a weakly differentiated race, and the differences between it and *C. b. brooksi* are significant only in view of the uniformity of the nominate race throughout its wide range. Recognition of *aranda* draws attention to the importance of the Central Highlands and the valley of the Finke as barriers to the dispersal of dune-inhabiting *Ctenotus*. Most other species of the western deserts have yet to be found to the east of these barriers.

Paratypes. "Central Australia, Horn Expedition" (NMV D1180, 1182, 1186). South Australia: Dalhousie (NMV D199, 207). Queensland: 14 mi. N of Fortville Tank (NMV D11997).

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TABLE 1

Number of specimens (number with original tail in brackets) and mean value of following characters: SVL (snout-vent length in mm); length of appendages (as % SVL); ratio width to height of second loreal; and number of midbody scale-rows, lamellae under fourth toe, supraciliaries, palpebrals, upper labials, ear lobules and nuchals. Data solely from material listed in accounts of species.

	N	SVL	Tail	Fore-leg	Hind leg	Loreal	Scale rows	Lamellae	Supraciliaries	Palpebrals	Labials	Ear lobules	Nuchals
p. ocellifer	52 (21)	73	172	25.4	39.2	1.01	34.9	23.3	6.9	11.3	8.1	1.7	3.0
p. calx	9 (5)	96	199	26.0	39.1	1.05	35.7	21.3	7.2	12.1	8.0	6.1	3.0
grandis	7 (3)	59	198	25.5	42.3	1.21	32.0	24.9	6.9	11.0	8.1	6.0	3.4
spaldingi	21 (7)	87	220	22.9	43.0	1.91	28.6	21.0	9.8	10.8	7.3	4.3	3.0
robustus	18 (4)	106	202	23.1	39.1	1.64	29.8	20.3	9.8	12.3	7.1	4.7	3.9
saxatilis	27 (7)	74	218	23.6	39.5	1.49	29.8	21.5	7.3	10.9	8.2	4.7	2.1
helenae	20 (7)	73	212	23.1	39.4	1.44	27.4	22.8	7.1	10.7	8.1	4.1	2.9
inornatus	146 (48)	67	245	24.5	43.6	1.41	29.7	21.7	8.1	11.1	8.0	4.8	2.8
joanae	1 (0)	47		25.0	41.0	1.40	26.0	19.5	7.0	8.5	8.0	2.5	5.0
leonhardii	77 (37)	60	200	25.6	45.1	1.52	28.8	23.7	7.0	10.4	8.1	4.6	3.7
hamptonensis	10 (7)	75	218	25.5	46.5	1.51	30.3	26.0	7.7	11.7	8.1	4.8	2.3
hilli	12 (6)	40	214	28.2	49.8	1.28	30.7	24.7	7.4	10.6	7.2	5.3	1.2
essingtonii	61 (20)	50	217	23.9	44.0	1.25	26.5	23.1	7.8	10.0	7.1	2.8	4.0
decaneurus	2 (1)	37	187	28.5	46.5	1.55	25.5	20.5	8.5	10.0	7.5	4.0	3.5
alacer	13 (1)	52	221	27.9	50.8	1.60	29.0	25.2	6.8	10.5	8.1	4.8	3.4
quattuordecimlineatus	12 (4)	51	226	27.0	45.4	1.33	27.8	24.8	6.8	11.0	8.1	4.1	2.5
dux	6 (3)	61	240	26.2	46.5	1.67	29.2	25.5	7.1	10.8	8.0	4.8	3.2
piankai	7 (4)	43	226	27.7	44.7	1.30	21.7	21.9	6.4	8.7	7.9	3.7	4.0
calurus	2 (1)	44	202	26.0	46.2	1.90	25.0	23.5	7.5	11.5	7.5	2.5	2.5
r. mesotes	6 (5)	38	217	26.4	45.4	1.75	24.0	24.2	6.0	9.7	7.7	2.1	3.7
s. schomburgkii	29 (14)	41	188	26.7	46.9	1.86	26.9	22.3	6.8	9.3	7.2	3.2	3.9
s. pallescens	1 (1)	39	182	27.0	48.9	1.53	29.0	20.3	7.0	9.2	7.0	3.5	3.8
strauchii	1 (1)	50	160	22.5	41.3	1.53	27.0	18.8	6.7	9.5	8.2	2.6	3.0
taeniatus	2 (1)	41	180	26.0	45.7	1.75	27.0	20.5	8.0	9.0	8.0	4.5	4.0
b. brooksi	43 (30)	39	182	27.7	50.8	1.92	25.2	24.6	6.7	9.5	7.5	3.0	3.4
b. aranda	7 (1)	44	159	25.2	43.6	2.08	26.0	22.1	6.4	10.2	7.7	3.0	3.9

13.—Concentrations of major nutrient elements in vegetation and soils from a portion of the Western Australian arid zone

by J. Keay and E. Bettenay *

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Abstract

Soil and plant samples from twenty-two sites representative of six ecological units were collected from central Western Australia where rainfall averages less than 10 inches (25.4 cm) per annum. Most soils are acid in reaction and have low levels of phosphorus and potassium as well as low cation exchange capacities. Only in limited areas are soils high in carbonate or soluble salts.

Concentrations of nitrogen and phosphorus, and nitrogen and sulphur were highly correlated. In the case of *Acacia aneura*, which was present on most sites, it was possible to illustrate a significant correlation between soil and foliar concentrations of phosphorus. *Acacia salicina* was found to have unusually high amounts of sulphur and calcium, and this was due to the presence of calcium sulphate apparently mainly on the external surface of the leaves.

Chenopods growing in saline environments have high concentrations of the cations sodium, potassium, calcium, and magnesium. *Salsola kali* and *Rhagodia gaudichaudiana* are distinguished from other chenopods by high contents of potassium relative to sodium.

Introduction

In 1965 the authors traversed central Western Australia on a route extending from Kalgoorlie, via Laverton and the Warburton Mission, to Giles, and returning to Mount Magnet via Carnegie Station, Wiluna and Meekatharra (Fig. 1). This area, for the greater part, lies outside the inhabited portion of the state and is thus little known and rarely visited. Consequently the opportunity was taken to collect samples of soils and plants from several soil-plant communities or ecosystems. Samples were later analysed to determine the concentration of the major elements in both foliage and soils, so that possible relationships between these could be studied.

Environment

Soil and vegetation samples were largely collected from the Gibson Desert, but some were taken from the pastoral districts which adjoins to the west (Fig. 1). The study area lies wholly within the Eremean botanical province, and includes parts of the mulga bush formation, *Triodia* steppe, and desert (Gardner 1942). A more detailed description of vegetation in the western portion has been given by Speck (see Mabbutt *et al*, 1963), while similar sand dune vegetations have been described by Eardley (1946, 1949) for the Simpson Desert in central Australia.

Climatic data are recorded at a number of stations within the area (Anon 1956, and Commonwealth Bureau of Meteorology unpublished data). In all cases annual average rainfall (Fig. 2) is less than 10 inches (25.4 cm), and ranges from 24 cm at Wiluna to 18 cm at Giles. Temperatures reach an average maximum of approximately 100°F (38°C) during December, January, February, and March, and an average minimum of about 40°F (4.5°C) during June, July, and August. As a result of the low and irregular rainfall, and extreme heat, perennial vegetation is almost entirely restricted to species able to survive for several years on rain insufficient to permit growth.

The area is a gently undulating plateau with elevations ranging from 400 metres to 525 metres, and with occasional stony ranges to 675 metres. Correlation between topography, vegetation, and soils is marked, and the following six broad ecological units may be recognised. Most extensive are broad *mulga plains* which have shallow soils commonly overlying siliceous hardpan (Teakle 1936, Mabbutt *et al.* 1963). There is normally a surface pavement composed of the more resistant of the country rocks, but this thins out towards the drainage lines where there is a general increase in the depth of soil cover. Slightly elevated above the mulga plains, and in places separated by small erosional scarps or breakaways, are *spinifex uplands* where soils are shallow and gravelly, and overlie duricrust formed from lateritic mottled zones. Ferricrete and silcrete are frequently exposed in the breakaways. Extensive dune fields, the *spinifex sandhills*, occur in the Gibson Desert area. They are largely associated with broad flats, and seldom extend onto the gravelly uplands. Where water relations are better than average, as on sandy outwash plains at the foot of rocky ranges, and on some of the less saline drainage lines, there are *Casuarina flats*. Elsewhere the main drainage lines, which are marked by strings of playa lakes and evaporate deposits, have *saltbush flats* on the more saline sections, and *eucalypt flats* on shallow calcareous soils overlying kankar.

Description of sample sites

Twenty-two sites representative of the six ecological units were sampled and are described in more detail below. At each site foliage of all prominent plants was collected, and the soil profile was sampled at depths of 0 to 3 inches (0-7.5 cm), 3 to 6 inches (7.5-15 cm), and 6 to

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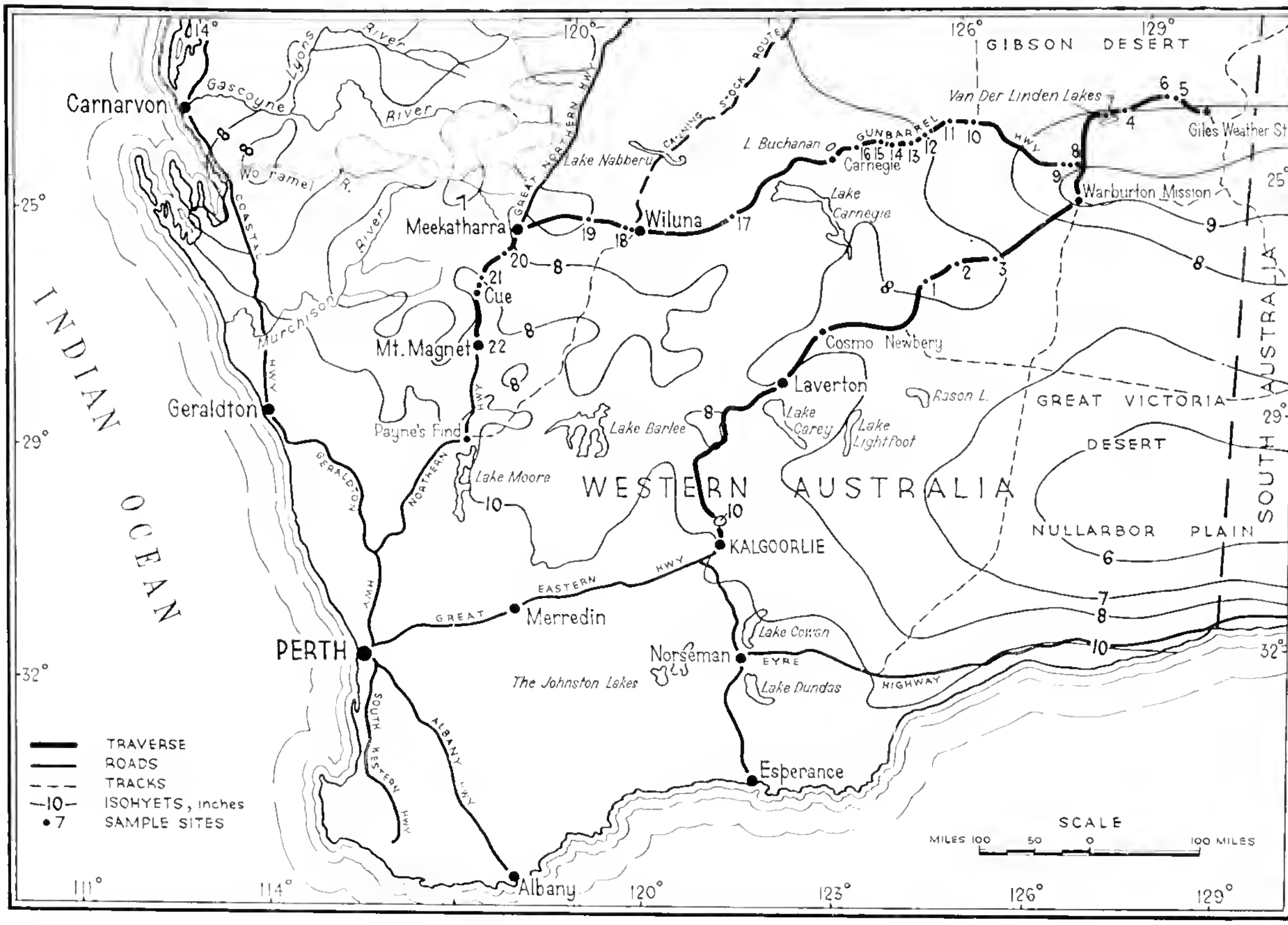

Figure 1.—Locality plan and traverse map showing isohyets of average annual rainfall in inches.

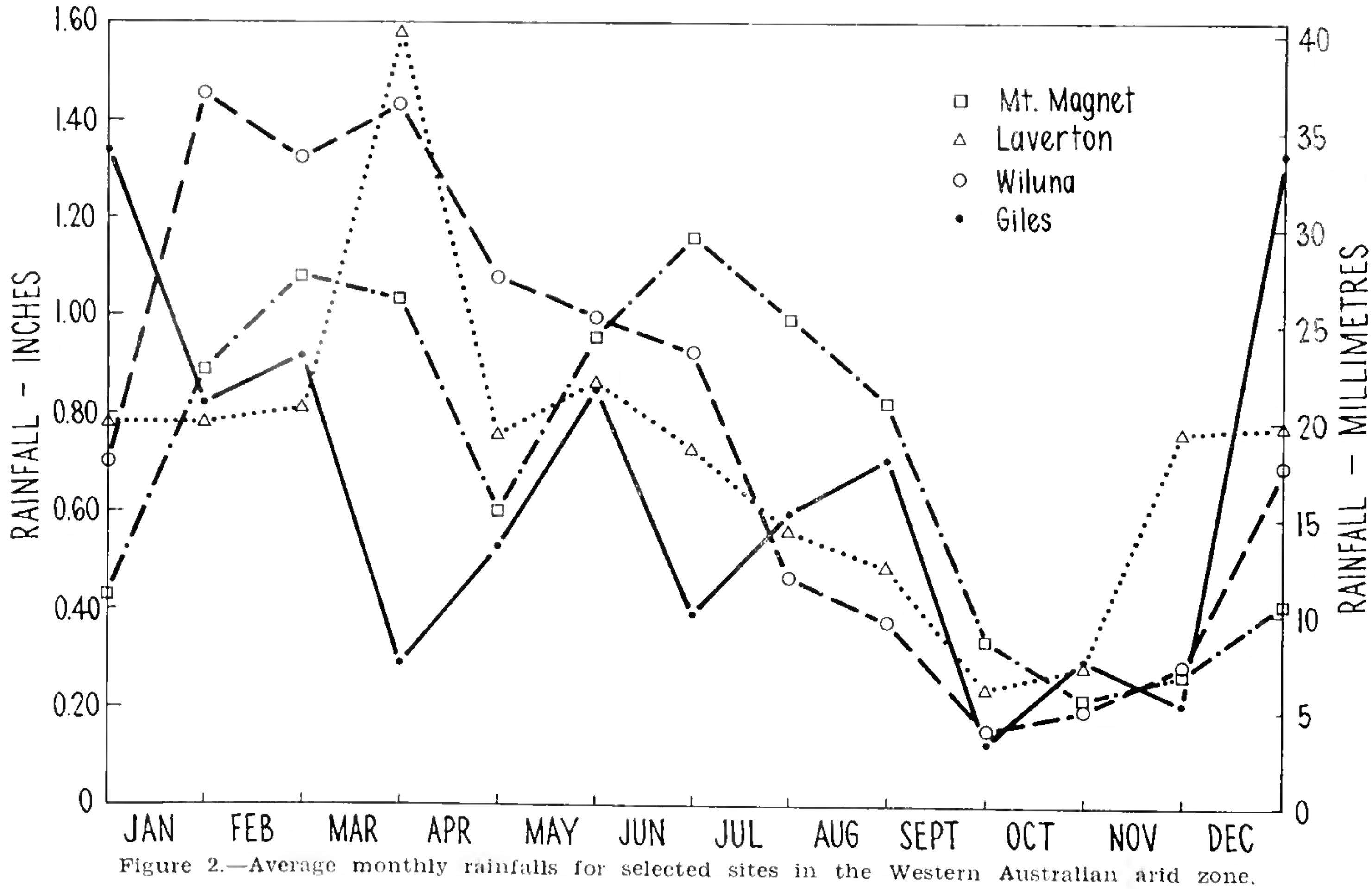

Figure 2.—Average monthly rainfalls for selected sites in the Western Australian arid zone.

12 inches (15-30.5 cm). Soils are described in terms of the keyed classification of Northcote (1965).

(1) *Mulga plains* (Sites 1, 2, 9, 12, 14, 19, 21): This unit (Fig. 5) is most extensive particularly in the pastoral districts, and is also found on erosion plains throughout the study area.

Soils range from red coherent sands (Uc1.43), and earthy sands with a slight increase in clay content at depth (Uc5.21), to red earthy loams (Um5.3), and neutral red earthy soils with a gradational increase in clay plus silt content with depth (Gn2.12). All overlie acid hardpan which is seldom greater than 40 inches and often less than 6 inches from the surface.

Vegetation is dominated by a tree cover of mulga (*Acacia aneura*) and other *Acacia* species, with occasional *Eucalyptus youngiana* and *Canthium latifolium*, often occurring in distinct bands, together with the shrubs *Eremophila latrobei* and spp, *Santalum lanceolatum*, *Cassia sturtii*, and *Ptilotus obovatus*. There is a variable ground cover of the grasses *Triodia pungens*, *T. basedowii*, and *Danthonia bipartita*.

(2) *Spinifex uplands* (Sites 8, 10, 11): This unit (Fig. 6) is extensive on Gunbarrel Highway between Fame Range and the Van der Linden Lakes, but also occurs in smaller patches elsewhere.

Soils show little variability, being red earthy sands, and sandy loams, which have a slightly higher clay content at depth; the whole profile is dominated by the gravel fraction (KS Uc5.21)*.

There is a continuous, though patchy cover of spinifex (*Triodia basedowii*), and scattered, stunted trees of mulga and gidgee (*Acacia pruinocarpa*), with *Hakea lorea*, *Anthobolus exocarpoides*, and mallee (*Eucalyptus kingsmillii*).

(3) *Spinifex sandhills* (Sites 3, 4, 15, 16): These (Fig. 7) largely occur below the spinifex uplands and are particularly extensive east of Lake Buchanan and Cosmo Newberry.

Dunes are composed of acid, red, loose sands (Uc1.23), while the soils of interdune corridors are more coherent with an earthy fabric and a slight increase in clay content at depth (Uc5.21).

Dune vegetation consists of scattered small trees of mulga and other *Acacia* species—particularly *A. salicina*, which is frequently parasitised by *Loranthus exocarpi*,—mallee (*Eucalyptus ewartiana* and spp), *Gyrostemon ramulosus*, *Grevillea stenobotrya*, and *Hakea rhombalis*. There is a low shrub cover of *Thryptomene maisonneuvii*, often occurring in dense thickets with *Helipterum adpressum*, *Crotalaria cunninghamii* and *Dicrastylis* sp. The grasses *Triodia pungens* and *Aristida nitidula* form a groundcover.

* The prefix KS here refers to gravels mainly composed of iron and aluminium oxides, which were probably formed in these soils by the breakdown of indurated mottled zone materials which commonly occur within 12 inches of the surface.

(4) *Casuarina flats* (Sites 5, 6, 7): These (Fig. 8) occur largely in the east of the area near some of the less saline drainage lines, and at the foot of rocky ranges where water relations are probably better than average.

Texturally soils are similar to those of the spinifex sandhills, being red loose sands (Uc1.23); but they are frequently alkaline at depth where drainage is impeded and there are associated kopi gypsum deposits.

Vegetation is dominated by large trees of desert oak (*Casuarina decaisneana*), with scattered *Acacia* spp—particularly *A. salicina*—mallee (*Eucalyptus gamophylla*), and quondong *Santalum acuminatum*). There is sparse shrub cover of *Eremophila* spp, *Cassia sturtii*, and *Thryptomene maisonneuvii*, together with *Alyogyne pinonianus*, *Ptilotus obovatus*, and *Dodonaea attenuata*, and the grasses *Triodia pungens*, *T. basedowii*, *Eragrostis* sp., and *Amphipogon strictus*.

(5) *Saltbush flats* (Sites 13, 17, 20, 22): These occur largely in sump situations representing former drainage lines, but are occasionally found on moderate slopes where seepage occurs.

Soils are rather variable, but are largely non-calcareous red sands (Uc1.23 and Uc1.43). Occasionally there are sands overlying acid hardpan at shallow depths (Uc5.13), and less often red soils with gradational texture profiles in which calcium carbonate is clearly visible throughout the solum (Gc1.22).

Vegetation is confined almost entirely to herbaceous shrubs and annuals of the chenopod family including saltbush (*Artriplex hymenotheca*, *A. inflata*, and *Rhagodia gaudichaudiana*), blue bush (*Kochia carnosa*, *K. pyramidata*), bindy-eye (*Bassia drummondii*, *B. gardneri*, *B. paradoxa*, *B. obliquicuspis*), and roly-poly (*Salsola kali*). On fringing areas and less saline ridges there is a variable cover of trees (*Acacia* spp, and *Hakea* sp.), and the shrubs *Cassia sturtii*, *Eremophila* spp, *Lycium australe*, *Hemichroa diandra*, and *Plagianthus* sp.

(6) *Eucalypt flats* (Site 18): This unit occurs largely in the upper sections of the saline drainage lines. It appears to be more common in the area where drainage is to the west coast, and here forms part of the Cunyu and Milcura land systems (Mabbutt *et al.* 1963).

Soils are typically loams in which there are large amounts of calcareous rubble (kankar) and a lime pan at shallow depth (Um5.11).

Characteristically vegetation consists of large trees of river gum (*Eucalyptus camaldulensis*), with scattered mulga, *Pittosporum phillyraeoides* and *Santalum lanceolatum*. There is a variety of shrubs and annuals including *Eremophila longifolia*, *Solanum lasiophyllum*, *Zygophyllum*, sp., *Cephalipterum* sp., and *Indigofera brevidens*.

Results

A complete list of plant species at each site, together with results of laboratory analysis of soil and foliage samples has been presented by

TABLE 1

Means and ranges of properties of soils from mulga plains
(Sites 1, 2, 9, 12, 14, 19, 21)

	SATURATION EXTRACT					EXCHANGEABLE CATIONS (m.e./100 g)				HCl SOLUBLE		
	% H_2O at saturation	Ec millimhos/cm at 20° C	pH sat. extract	pH 1:2½ M/100	C.E.C. m.e./100 g KCl	Na	K	Ca	Mg	% P	% K	% Na
0–3"	20 (17–24)	0·19 (0·09–0·26)	5·7 (4·4–7·3)	4·6 (3·8–6·2)	3·3 (2·1–5·6)	0·08 (0·01–0·20)	0·31 (0·1–0·65)	0·80 (0·05–1·6)	0·30 (0·05–1·1)	0·020 (0·006–0·042)	0·047 (0·030–0·087)	0·016 (0·006–0·033)
3–6"	20 (15–25)	0·26 (0·12–0·46)	5·1 (4·2–6·4)	4·3 (3·8–5·0)	3·3 (2·3–5·9)	0·08 (0·01–0·27)	0·25 (0·12–0·56)	0·91 (0·05–1·4)	0·30 (0·05–1·4)	0·018 (0·005–0·035)	0·045 (0·027–0·075)	0·017 (0·009–0·036)
6–12"	20 (16–25)	0·37 (0·10–0·91)	5·1 (4·2–6·1)	4·4 (3·8–5·4)	3·2 (2·4–6·1)	0·09 (0·01–0·34)	0·24 (0·14–0·48)	0·88 (0·05–1·8)	0·29 (0·05–1·0)	0·017 (0·005–0·032)	0·049 (0·025–0·085)	0·017 (0·009–0·041)

TABLE 2

Means and ranges of properties of soils from upland gravel plains
(Sites 8, 10, 11)

	SATURATION EXTRACT					EXCHANGEABLE CATIONS (m.e./100 g)				HCl SOLUBLE		
	% H_2O at saturation	Ec millimhos/cm at 20° C	pH sat. extract	pH 1:2½ M/100	C.E.C. m.e./100 g KCl	Na	K	Ca	Mg	% P	% K	% Na
0–3"	19 (17–20)	0·12 (0·11–0·16)	5·4 (4·9–5·8)	4·2 (4·1–4·3)	2·4 (2·0–2·6)	0·05 (0·01–0·11)	0·10 (0·08–0·12)	0·35 (0·15–0·6)	0·15 (0·15–0·15)	0·012 (0·009–0·013)	0·023 (0·020–0·026)	0·012 (0·012–0·013)
3–6"	20 (19–20)	0·16 (0·13–0·20)	5·2 (4·4–6·1)	4·2 (4·2–4·2)	2·4 (2·0–2·7)	0·01 (0·01–0·02)	0·13 (0·10–0·14)	0·38 (0·15–0·5)	0·17 (0·15–0·2)	0·011 (0·009–0·012)	0·025 (0·020–0·031)	0·013 (0·012–0·014)
6–12"	19 (19–20)	0·19 (0·13–0·30)	5·3 (4·8–5·9)	4·4 (4·3–4·6)	2·6 (2·2–3·2)	0·04 (0·04–0·04)	0·16 (0·13–0·19)	0·62 (0·2–1·25)	0·23 (0·15–0·2)	0·011 (0·009–0·010)	0·028 (0·023–0·037)	0·014 (0·013–0·015)

Keay and Bettenay*. They are further discussed below in order of soil-plant communities described in the previous section.

a. *Soil properties*

(1) *Mulga plains*.—These soils are characteristically acid, with about half of the exchange capacity saturated with bases (Table 1). Concentrations of acid-soluble phosphorus are low, and the mean values for chemical properties show little variation with depth.

(2) *Spinifex uplands*.—The high content of gravel (>2mm fraction) further dilutes the very low concentrations of plant nutrient which are expressed in Table 2 in terms of the fraction <2mm. The matrix is acidic with only about one third of the exchange capacity occupied by bases. Chemical properties are uniform within the top twelve inches.

* C.S.I.R.O. Division of Soils, Adelaide, Tech. Mem. 18/67 available on request.

(3) *Spinifex sandhills*.—These soils have the lowest cation exchange capacities and acid-soluble phosphorus concentrations of all soils examined (Table 3). The highest concentration of acid-soluble phosphorus is 50 ppm, and assuming 10^6 lb soil/acre—3 inches, represents only 50 lb P/acre.

Although the soils are acidic, the exchange complex is almost saturated with bases, the dominant cations being calcium and magnesium. The measurement of such small quantities of exchangeable cations etc. involves relatively large laboratory error, but the values for pH, cation exchange capacity and acid-soluble phosphorus and potassium cover a narrow range of values, and do not vary with depth.

(4) *Casuarina flats*.—Chemically these soils are similar to sandhill soils, but have higher concentrations of acid-soluble phosphorus and potassium (Table 4). The pH and cation ex-

change capacity values are also higher than in the dune soils.

(5) *Saltbush flats.*—The soils of this unit are characteristically saline (Table 5) although some surface soils are not high in soluble salts. Soils are neutral in reaction, with about 40% of the exchange complex occupied by bases. Levels of acid-soluble phosphorus, potassium, and sodium are higher than in most soils examined.

TABLE 3

Means and ranges of properties of soils from spinifex sandhills
(*Sites* 3, 4, 16)

	SATURATION EXTRACT					EXCHANGEABLE CATIONS (m.e./100 g)				HCl SOLUBLE		
	% H_2O at saturation	Ec millimhos/cm at 20° C	pH sat. extract	pH 1:2½ M/100	C.E.C. m.e./100 g KCl	Na	K	Ca	Mg	% P	% K	% Na
0–3″	21 (20–22)	0·23 (0·094–0·49)	5·9 (5·3–6·5)	5·7 (5·3–6·0)	0·87 (0·8–1·0)	0·03 (0·01–0·04)	0·05 (0·04–0·06)	0·27 (0·2–0·3)	0·13 (0·1–0·2)	0·0033 (0·0024–0·0044)	0·007 (0·005–0·01)	0·003 (0·001–0·004)
3–6″	22 (21–22)	0·20 (0·06–0·42)	5·8 (5·3–6·2)	5·6 (5·0–5·2)	0·80 (0·5–1·4)	0·06 (0·02–0·12)	0·037 (0·04–0·07)	0·35 (0·2–0·45)	0·10 (0·1–0·1)	0·0034 (0·0023–0·0048)	0·008 (0·005–0·013)	0·003 (0·001–0·004)
6–12″	20 (19–20)	0·22 (0·06–0·49)	5·9 (5·5–6·2)	5·1 (4·9–5·2)	0·53 (0·2–0·9)	0·04 (0·01–0·08)	0·033 (0·04–0·07)	0·20 (0·1–0·3)	0·10 (0·1–0·1)	0·0030 (0·0023–0·0041)	0·007 (0·005–0·012)	0·003 (0·001–0·004)

TABLE 4

Means and ranges of properties of soils from Casuarina *flats*
(*Sites* 5, 6, 7)

	SATURATION EXTRACT					EXCHANGEABLE CATIONS (m.e./100 g)				HCl SOLUBLE		
	% H_2O at saturation	Ec millimhos/cm at 20° C	pH sat. extract	pH 1:2½ M/100	C.E.C. m.e./100 g KCl	Na	K	Ca	Mg	% P	% K	% Na
0–3″	16 (14–17)	0·20 (0·12–0·29)	7·0 (6·2–7·3)	6·0 (5·0–7·1)	1·7 (0·9–2·3)	0·07 (0·04–0·08)	0·14 (0·05–0·25)	1·22 (0·4–2·0)	0·27 (0·1–0·4)	0·0052 (0·0043–0·0069)	0·030 (0·017–0·037)	0·004 (0·003–0·005)
3–6″	16 (15–17)	0·25 (0·16–0·35)	6·7 (5·5–7·8)	6·1 (4·7–7·5)	1·8 (1·2–2·4)	0·08 (0·04–0·12)	0·15 (0·06–0·26)	1·25 (0·3–2·35)	0·27 (0·15–0·4)	0·0045 (0·0038–0·0056)	0·031 (0·020–0·037)	0·005 (0·004–0·005)
6–12″	16 (16–16)	0·22 (0·12–0·35)	6·1 (5·1–7·9)	6·1 (4·6–7·7)	1·8 (1·1–2·5)	0·05 (0·04–0·08)	0·16 (0·10–0·24	1·30 (0·3–2·5)	0·20 (0·1–0·3)	0·0042 (0·0036–0·0051)	0·032 (0·020–0·041)	0·005 (0·004–0·006)

TABLE 5

Means and ranges of properties of soils from saline areas
(*Sites* 13, 17, 20, 22)

	SATURATION EXTRACT					EXCHANGEABLE CATIONS (m.e./100 g)				HCl SOLUBLE		
	% H_2O at saturation	Ec millimhos/cm at 20° C	pH sat. extract	pH 1:2½ M/100	C.E.C. m.e./100 g KCl	Na	K	Ca	Mg	% P	% K	% Na
0–3″	18 (13–21)	1·24 (0·14–2·05)	7·1 (6·1–8·0)	6·7 (5·5–7·8)	6·3 (1·1–11·1)	0·54 (0·02–1·3)	0·64 (0·19–1·44)	0·93 (0·5–1·5)	0·28 (0·1–·04)	0·015 (0·013–0·017)	0·13 (0·03–0·25)	0·04 (0·008–0·093)
3–6″	21 (16–24)	2·30 (0·11–4·90)	7·1 (6·0–8·1)	7·0 (5·7–8·4)	6·7 (0·8–13·3)	0·18 (0·02–0·3)	0·69 (0·2–0·25)	0·75 (0·7–0·8)	0·35 (0·3–0·4)	0·016 (0·013–0·023)	0·22 (0·03–0·61)	0·09 (0·008–0·26)
6–12″	25 (16–36)	4·56 (0·14–8·06)	7·3 (6·3–8·2)	7·2 (5·8–8·2)	4·5 (0·9–11·2)	0·51 (0·02–1·0)	0·25 (0·24–0·26)	0·80 (0·7–0·9)	0·40 (0·35–0·45)	0·014 (0·010–0·020)	0·20 (0·04–0·53)	0·14 (0·008–0·33)

TABLE 6

Properties of the soil from a eucalypt flat
(Site 18)

	SATURATION EXTRACT					EXCHANGEABLE CATIONS (m.e./100 g)				HCl SOLUBLE		
	% H_2O at saturation	Ec millimhos/cm at 20° C	pH sat. extract	pH 1:2½ M/100	C.E.C. m.e./100 g KCl	Na	K	Ca	Mg	% P	% K	% Na
0–3″	34	0·49	8·1	7·8						0·022	0·39	0·041
3–6″	43	0·32	8·3	7·9						0·018	0·43	0·041
6–12″	49	0·28	8·2	7·9						0·017	0·39	0·045

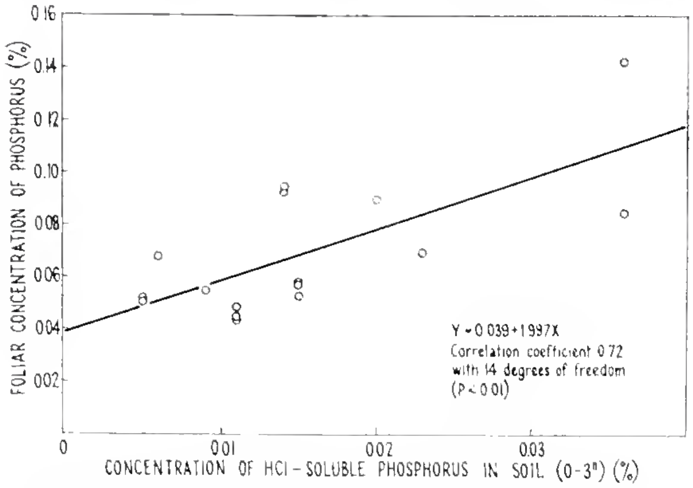

Figure 3.—The relationship between soil and foliar phosphorus concentrations in *Acacia aneura*.

(6) *Eucalypt flats*.—Only one site was examined, and the chemical properties of the soil are given in Table 6. It is alkaline in reaction, and has higher concentrations of acid-soluble phosphorus and potassium than all other soils.

b. *Foliar concentrations of nutrients*

The mean concentrations of each nutrient in the species sampled are given in Table 7. The number of samples for each mean is given in parenthesis.

Nitrogen concentrations are generally low, the grasses having the lowest values and the halophytes the highest. Nitrogen fixing species have concentrations between 1% and 2% in their dried foliage. Concentrations of phosphorus are low in almost all species, while potassium concentrations vary between wide limits, being lowest in the grasses and very high in a few specific plants notably *Rhagodia gaudichaudiana*, *Salsola kali* and *Calandrinia balonensis*. Sodium concentrations are generally low except in the halophytes, in which values are as high as 11% of the dried foliage. The concentrations of calcium vary widely with the grasses again having the lowest concentrations; occasionally a high concentration of calcium is accompanied by a high concentration of sulphur. Magnesium concentrations show a tendency to vary in the same way as calcium concentrations, although the values are generally lower. An exception is *Atriplex inflata* which has a higher concentration of magnesium than calcium. Sulphur concentrations are generally higher than those of phosphorus, with

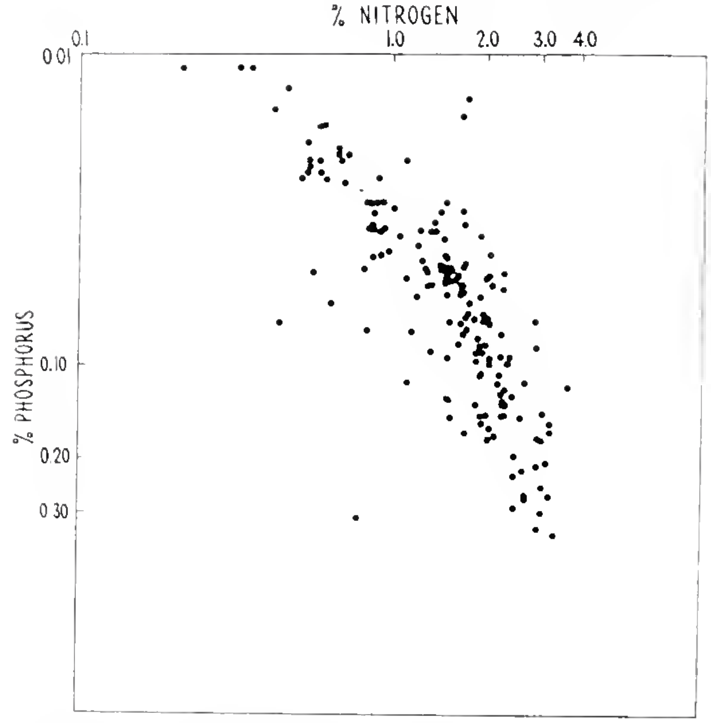

Figure 4.—The relationship between nitrogen and phosphorus concentrations in the foliage of all species.

occasional very high values, notably in *Acacia salicina and Gyrostemon ramulosus*. This is further discussed below.

Discussion

The soils at all sites, in common with most other Australian soils, have low or very low levels of phosphorus. Wild (1958) has attributed this to loss of phosphorus by weathering. Beadle (1962) considers it to be in many cases the result of the low concentrations of phosphorus in the rocks from which soils are derived. It seems probable that both are factors in the low content of phosphorus in these soils.

Acacia aneura occurred on several sites, and there was a significant correlation ($P<0.01$) between the concentration of phosphorus in the foliage and the soil phosphorus extracted by hot 5N HCl (Figure 3). The relationship between the nitrogen and phosphorus concentrations in the foliage of all species after logarithmic transformations is shown in Figure 4. The concentrations of the two elements are highly correlated ($r = 0.784$ with 125 degrees of freedom, $P<0.001$). Nitrogen and sulphur concentrations are also correlated, but to a lesser degree ($r = 0.484$ with 125 degrees of freedom, $P<0.001$).

One species, *Acacia salicina*, has unusually high concentrations of sulphur in its foliage, and since this is accompanied by similar high concentrations of calcium the foliage was tested for water soluble calcium sulphate. The presence of calcium sulphate was confirmed by shaking the ground leaf material with water for a few seconds and testing the extract with acetone. Microscopic examination* failed to detect crystalline gypsum in the tissues, and the calcium sulphate appeared to be concentrated on the external surface of the foliage. The possibility of a wind-blown deposit is considered unlikely since some of the sites were not near soils containing gypsum, and other species from

* We are indebted to Professor B. J. Grieve of the Department of Botany, Western Australian University, for this examination.

TABLE 7

The mean concentrations of nutrients in the species sampled

Species	No. of Samples	% N	% P	% K	% Na	% Ca	% Mg	% S
Aristida nitidula	(4)	0.40	0.015	0.23	0.02	0.33	0.06	0.08
Eragrostis sp.	(2)	0.60	0.024	0.31	0.01	0.24	0.09	0.08
Triodia basedowii	(8)	0.55	0.017	0.31	0.04	0.36	0.07	0.08
T. pungens	(5)	0.80	0.025	0.44	0.05	0.26	0.07	0.07
Danthonia bipartita	(1)	2.7	0.12	1.3	0.02	0.57	0.26	0.22
Casuarina decaisneana	(4)	1.1	0.033	0.83	0.04	1.2	0.18	0.11
Grevillea stenobotrya	(1)	0.7	0.022	0.45	0.06	6.2	0.22	0.20
Anthobolus exocarpoides	(2)	1.9	0.018	1.9	0.10	1.5	0.36	0.28
Hakea lorea	(2)	0.80	0.027	0.85	0.01	0.56	0.18	0.20
H. rhombalis	(1)	0.60	0.022	0.36	0.12	0.59	0.14	0.15
H. arida	(1)	0.80	0.031	0.75	2.5	1.9	0.13	1.0
Santalum lanceolatum	(2)	2.1	0.082	1.1	0.05	1.7	0.32	0.58
S. acuminatum	(1)	1.0	0.031	0.94	0.57	5.3	0.46	0.27
Rhagodia gaudichaudiana	(1)	3.2	0.20	10.2	4.0	1.5	0.94	0.29
Atriplex hymenotheca	(3)	2.0	0.11	2.8	7.0	1.5	0.78	0.46
*A. inflata**	(2)	3.1	0.28	3.2	5.9	1.4	2.1	0.29
Bassia drummondii	(1)	1.9	0.086	1.5	7.1	1.1	0.35	0.19
B. gardneri	(1)	1.9	0.11	2.0	8.9	1.6	0.39	0.23
B. paradoxa	(1)	1.8	0.13	2.2	3.8	0.87	0.36	0.24
B. obliquicuspis	(1)	1.9	0.14	2.4	2.4	1.5	0.43	0.18
B. sp.	(1)	2.2	0.13	2.0	5.6	1.4	0.34	0.20
Salsola kali	(2)	2.6	0.12	8.9	1.7	2.2	1.2	0.16
Kochia pyramidata	(2)	2.8	0.13	2.5	8.7	1.0	0.82	0.24
K. carnosa	(2)	2.3	0.14	2.4	5.4	0.60	1.2	0.25
K. sp.	(3)	2.0	0.085	3.0	11.0	0.82	0.58	0.31
Hemichroa diandra	(1)	1.9	0.090	2.6	3.8	3.7	2.7	1.0
Ptilotus obovatus	(4)	2.1	0.069	3.0	0.03	1.9	1.6	0.16
Gyrostemon ramulosus	(1)	3.6	0.12	1.3	0.28	4.5	0.77	1.8
Calandrinia balonensis	(1)	2.1	0.051	8.6	0.02	0.67	1.9	0.17
Pittosporum phillyraeoides	(1)	1.2	0.11	2.7	0.04	1.5	0.42	0.18
Acacia aneura	(16)	1.7	0.067	0.79	0.02	1.3	0.19	0.11
A. salicina	(7)	1.5	0.043	0.80	0.05	5.7	0.52	2.4
A. dictyophleba	(2)	1.4	0.045	0.69	0.01	0.51	0.19	0.09
A. kempeana	(1)	1.7	0.052	0.92	0.02	1.1	0.20	0.12
A. helmsiana	(1)	1.5	0.030	0.59	0.21	0.98	0.32	0.09
A. sibirica	(1)	1.4	0.035	0.81	0.02	1.4	0.20	0.08
A. tetragonophylla	(2)	1.5	0.054	0.83	0.03	0.80	0.28	0.09
A. exocarpoides	(1)	1.2	0.077	0.82	0.13	0.70	0.21	0.40
A. pruinocarpa	(4)	1.9	0.054	0.77	0.02	1.4	0.55	0.13
A. sp.	(4)	1.6	0.04	0.66	0.02	1.0	0.19	0.13
Cassia sturtii	(3)	2.1	0.11	0.98	0.07	1.6	0.21	0.16
Crotalaria cunninghamii	(1)	2.9	0.087	0.68	0.02	0.57	0.31	0.23
Indigofera brevidens	(1)	2.4	0.12	0.97	0.04	5.3	0.53	0.16
Zygophyllum sp.	(1)	3.3	0.15	2.7	0.06	9.8	0.74	0.55
Dodonaea attenuata	(2)	1.8	0.079	1.6	0.01	0.69	0.27	0.18
Alyogyne pinoniana	(1)	1.6	0.085	1.0	0.04	1.0	0.47	1.0
Plagianthus sp.	(1)	2.5	0.22	1.2	3.1	2.2	0.73	0.82
Thryptomene maisonneuvii	(5)	0.90	0.031	0.39	0.02	1.5	0.22	0.11
Eucalyptus youngiana	(1)	0.90	0.030	0.51	0.22	0.67	0.21	0.09
E. ewartiana	(1)	0.90	0.034	0.51	0.01	1.5	0.27	0.09
E. gamophylla	(2)	1.0	0.037	0.51	0.28	1.3	0.34	0.10
E. kingsmillii	(1)	0.90	0.041	4.2	0.01	1.1	0.14	0.07
E. camaldulensis	(1)	1.3	0.089	0.85	0.03	0.90	0.43	0.12
E. sp.	(2)	0.85	0.047	0.56	0.01	0.59	0.28	0.11
Dicrastylis sp.	(3)	1.3	0.055	0.57	0.01	0.95	0.33	0.15
Lycium australe	(2)	2.3	0.16	1.9	9.4	2.9	1.6	0.55
Solanum lasiophyllum	(2)	2.6	0.14	2.0	0.02	1.1	0.31	0.23
Eremophila latrobei	(5)	2.3	0.10	2.2	0.02	1.2	0.33	0.20
E. cuneifolia	(2)	1.2	0.051	2.2	0.02	1.5	0.19	0.16
E. leucophylla	(2)	2.0	0.12	2.4	0.01	1.0	0.29	0.24
E. longifolia	(1)	1.5	0.14	1.9	0.01	0.62	0.17	0.13
E. foliosissima	(1)	2.3	0.12	2.3	0.01	0.82	0.18	0.17
E. pterocarpa	(2)	2.5	0.24	1.4	1.6	1.4	0.18	0.85
E. fraseri	(1)	2.0	0.14	1.4	0.05	1.5	0.37	0.22
E. sp.	(2)	1.3	0.050	1.3	0.02	0.81	0.27	0.14
Canthium latifolium	(2)	1.5	0.041	0.65	0.02	1.6	0.15	0.83
Scaevola spinescens	(1)	2.0	0.070	2.4	0.01	0.90	0.38	0.22
Helipterum adpressum	(1)	1.2	0.060	0.87	0.01	0.81	0.16	0.41
Cephalipterum sp.	(1)	2.8	0.14	2.7	0.02	1.9	0.34	0.19
* *A. inflata* (New South Wales) (Beadle, Whalley and Gibson 1957)		2.7	0.18	1.5	7.4	0.56		

Figure 5.—Mulga (*Acacia aneura* and spp) occurs on broad plains, particularly in the western half of the area inspected.

Figure 6.—Spinifex (*Triodia* spp) occurs on gravelly uplands, together with scattered trees of *Acacia*, *Hakea* and *Eucalyptus*.

Figure 7.—Dune vegetation is of scattered trees of *Acacia* spp with a low shrub cover of *Thryptomene maisonneuvii* and extensive spinifex (*Triodia* spp).

Figure 8.—Desert oak (*Casuarina decaisneana*) occurs on restricted flats, particularly near some of the less saline drainage lines.

the same sites have no accumulation of calcium sulphate on their foliage. The deposition of gypsum on the outer surface of the leaf could be explained by the evaporation of a leaf exudate, but the reason for the specific composition is not evident.

Several other species have high concentrations of sulphur: *Hakea arida*, *Hemichroa diandra*, *Gyrostemon ramulosus*, and *Alyogyne pinonianus* all have 1% or more sulphur in the dried foliage. These species also have relatively high concentrations of calcium, but since only a single specimen of each was collected, the entire sample was ground prior to analysis, and the same microscopic examination was not possible. The foliage samples could not be standardised by age or position, and consequently the high variability can be expected to allow only gross differences between species to appear. The effect of age would be particularly pronounced on the potassium and calcium concentrations, but would also occur on the other elements. Where single specimens were collected a high calcium content could be a reflection of a predominance of old tissue in the sample.

The concentrations of sodium, potassium, calcium, and magnesium, in m.equiv./g dry-weight, for all samples of *Atriplex*, *Salsola*, *Kochia*, and *Bassia* is given in Table 8. The sums of the four cationic concentrations vary by

TABLE 8

The concentrations (m. equiv./g dry-weight) of cations in some halophytes

	K	Na	Ca	Mg	*Sum*
Atriplex hymenotheca	0·73	3·07	0·73	0·65	5·18
A. inflata	0·83	2·59	0·68	1·75	5·85
Kochia pyramidata	0·64	3·77	0·50	0·63	5·54
K. carnosa	0·62	2·38	0·30	1·00	4·30
K. sp.	0·77	4·77	0·41	0·48	6·43
Salsola kali	2·28	0·78	1·12	0·98	5·16
Bassia drummondii	0·39	3·09	0·58	0·30	4·36
B. gardneri	0·52	3·87	0·78	0·32	5·49
B. paradoxa	0·57	1·67	0·44	0·30	2·98
B. obliquicuspis	0·63	1·05	0·73	0·38	2·79
B. sp.	0·50	2·44	0·71	0·28	3·93

only a factor of two, while the concentrations of sodium and potassium vary by a factor of about six. Within the first three genera the total concentrations of cations cover an even narrower range. The values for *Atriplex inflata* may be compared with values reported by Osmond (1966) for the same species grown in the field. He found calcium and magnesium concentrates of 0.68 and 1.47 m.equiv/g dry-weight respectively compared with 0.68 and 1.75 m.equiv./g dry-weight in the present samples. Analytical data were also reported by Beadle, Whalley, and Gibson (1957) for a range of *Atriplex* species, and for two samples of *A. inflata* they found the concentrations given in the footnote to Table 7. The concentrations found in the three different regions were similar.

Among the halophytes *Salsola kali* and *Rhagodia gaudichaudiana* are distinguished from the others in having very high concentrations of potassium and relatively low concentrations of sodium. The other chenopods have a high concentration of sodium and a relatively low concentration of potassium. The strong specificity for potassium uptake in these two species presumably arises in the roots, and implies a highly selective mechanism for the exclusion of sodium, which is not shared to the same degree by the other halophytes examined. All plants are able to concentrate potassium against a concentration gradient between the cell contents and the soil solution, but the concentrations in the dry-matter of *Salsola kali* and *Rhagodia gaudichaudiana* are unusually high.

Osmond (1966) examined the uptake of cations by *Atriplex* and suggested that the two processes could be involved, a 'specific' process involving cell metabolism and a 'luxury' process, possibly independent of metabolism, which operated at high concentrations of the nutrient solution. While such a passive process may account adequately for the cationic composition of most halophytes, the different ratios of potassium to sodium found between *Salsola kali* and *Rhogodia gaudichaudiana* and the other halophytes growing in close proximity suggests that specificity may extend into the higher concentration ranges for these species.

The single specimen of *Calandrina balonensis* also has a high concentration of potassium although growing in a non-saline environment.

Acknowledgements

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14.—The Archean succession to the west of Lake Lefroy

By G. J. H. McCall*

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Abstract

This paper summarises and correlates work carried out on the early Precambrian Kalgoorlie System (c. 2700 m.y. metamorphic age), in the area to the west of Lake Lefroy, by the author and by five students whose work he supervised. It includes a map of the entire area, a statement of the stratigraphy derived, and general accounts of the physiography and geology, including notes on the overall structural pattern and possible correlations with better known sequences to the north and south, at Kalgoorlie, Coolgardie and Norseman. While the synthesis is based on the results obtained by all six geologists, the conclusions drawn are entirely the responsibility of the author named. It is intended to publish further accounts giving the results of the investigations of certain sub-areas in more detail.

The stratigraphy deduced involves seven sedimentary units, together with a number of ophiolite belts: of the seven sedimentary units, three are exposed to the east and four to the west of a dislocation, the Yilmia dislocation, which appears to have a significant sinistral transcurrent displacement. The three eastern units are believed to be equivalent to the lower three of the four western units. Any stratigraphic resolution of this area must involve the acceptance of significant lateral thinning and thickening—that is, an essentially lensed sequence, whether by tectonic or sedimentological agencies or a combination of both. Another dislocation separates the eastern three units from the Kambalda ophiolites; no detailed stratigraphy is given for these, which are much better known by the geologists of the Western Mining Corporation. However, the major structure, a synclinorium, deduced from unequivocal facing indications, seems to require that the nickel sulphide bearing ophiolites of Kambalda are, broadly speaking, stratigraphically equivalent to similar nickel sulphide bearing ophiolites, associated with only thin, dominantly pelitic metasediment intercalations, that extend from Widgiemooltha southwards through Higginsville.

Introduction

Early in 1964 an area to the west of Lake Lefroy, in which rocks of the early Precambrian Kalgoorlie System are exposed, was selected as the subject of a detailed field and laboratory study, to be carried out by a group of workers over a period of several years. This particular area was chosen on account of excellent lake-shore exposures of fresh metamorphic and igneous rocks, and because of the peculiar problem posed by the porphyroid conglomerates: and it was also thought that such a programme might lead to the establishment of the geological succession from Red Hill (Kambalda), a point on the southerly continuation of the Golden Mile "greenstone" (ophiolite) belt, southwards to Widgiemooltha—from which point an extension of mapping could later be carried out southwards to Norseman, thus connecting up the two gold mining areas about which much is known of the geology and stratigraphy (Bekker, 1963: Woodall, 1965).

The objects of these investigations were:

a. establishment of a stratigraphic sequence.

b. study of primary structures and texture of the sediments, and the palaeogeography.

c. study of the regional metamorphism: with particular reference to testing the validity of the *Green Schist Facies* as defined by Turner and Verhoogen (1960).

d. Investigation of the nature and origin of the "porphyroid conglomerates"—rocks which have the character of albite porphyries, but contain traces of conglomeratic structure, and show atypical cal microtextures.

e. investigation of the complex meta-igneous basic and ultrabasic rock belts: commonly called "greenstone" belts, but perhaps, better referred to as "ophiolites", special attention being paid to igneous associations.

f. investigation of the post-metamorphic, east-west trending, dolerite dykes on a regional scale, with particular reference to the problem of the alkalic basalt and tholeiitic basalt associations.

g. to deduce the regional tectonic structure.

The first stage of this programme, mapping to Widgiemooltha, was completed at the end of 1966. The six geologists concerned, J. C. Braybrooke, J. J. G. Doepel, G. J. H. McCall, D. D. Middleton, P. C. Muhling and W. R. O'Beirne, have contributed. The author has supervised the entire project; W. R. O'Beirne, while engaged on a thesis study for the Ph.D. Degree, has concentrated on the problem of porphyroid metasomatism with him; the remaining four geologists have been engaged in thesis studies for the Degree of B.Sc. with honours (approximately equivalent to the Masters Degree in America) and have mapped individual sub-areas in detail.

The area mapped is shown in Figure 1, and in detail in Figures 2, 3 and 4, which also show the component sub-areas covered in the field by individual geologists.

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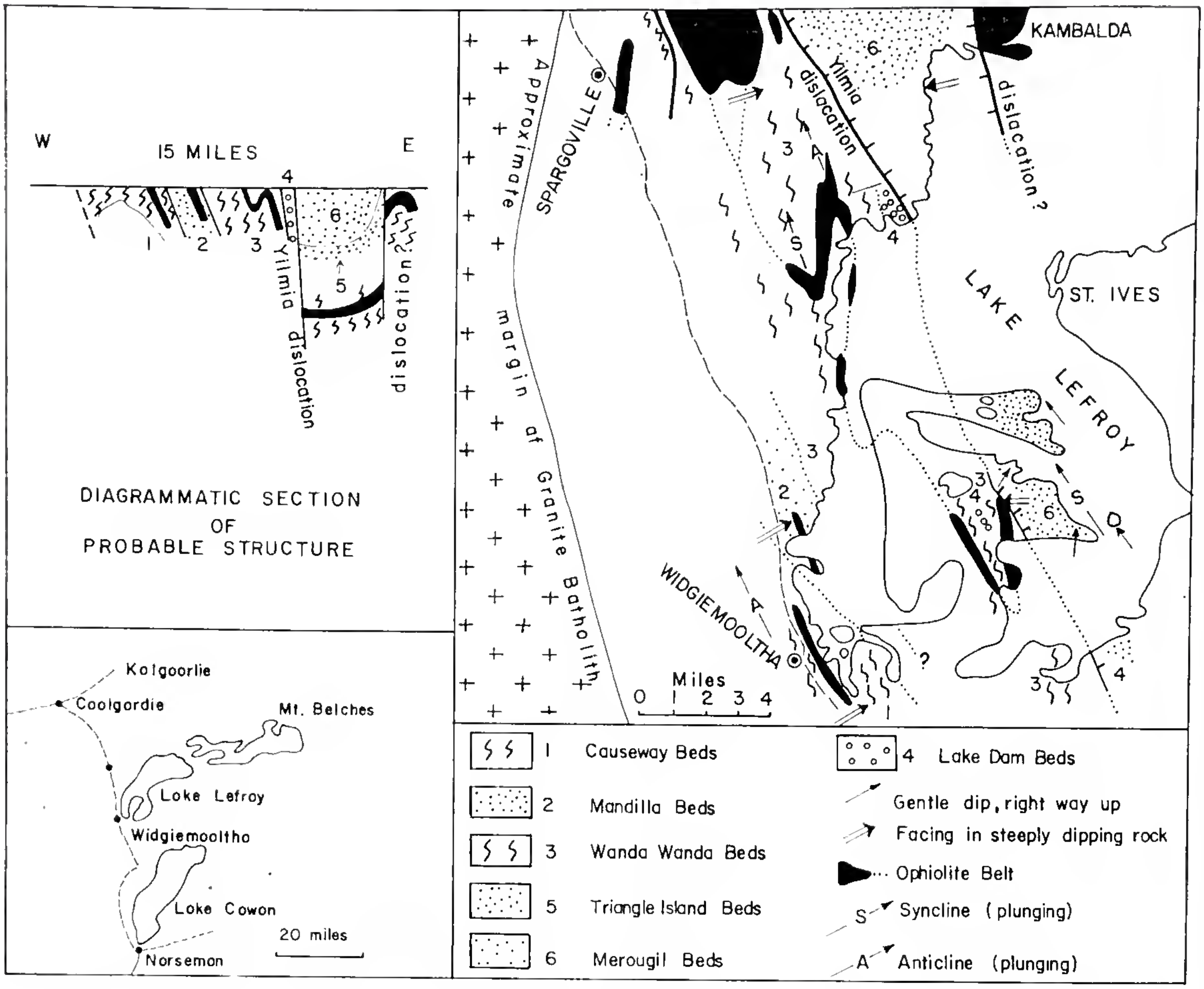

Figure 1.—(a) Location diagram. (b) Stratigraphic and structural relationships of the various rock units of the area. (c) Diagrammatic section across the area.

The area lies between the western shore of Lake Lefroy and the Coolgardie-Esperance Highway; extending from the latitude of Spargoville and Red Hill in the north to a point one mile south of Widgiemooltha. The "Lefroy Peninsula"* is also included. The lake area is solid ground for most of the year, Lake Lefroy being a saltpan which is only seasonally covered by a thin sheet of salty water, which moves erratically from side to side with change of wind.

The method of mapping used was:

a. Detailed coverage of sub-areas a mile or two in diameter, using air-photographs (40 chains to the inch sets of the Lands and Surveys Department and flights of low level photos taken for the Western Mining Corporation before the World War, and available either on the scale of 600 feet to the inch or on 1,200 feet to the inch).

* informal name, coined for convenience by the writer G. J. H. McCALL.

Sub-areas mapped in this way were:

Merougil Creek—J.C.B., D.D.M. (3 weeks)

Yilmia Hill—J.J.G.D. (3½ weeks)

Bayley's Workings (Pilbailey Hill, southern part)—P.C.M. (5 weeks)

Widgiemooltha—G.J.H.M., W.R.O'B. (3 weeks)

Lefroy Peninsula—G.J.H.McC. (1½ weeks)

Emu Well—G.J.H. McC (4 weeks)

b. The remainder of the area, much of which is inland terrain of sparse poor-quality exposure, was mapped by G. J. H. McCall, mainly by traverses along tracks and through the bush. The coastal area near Lake Dam, the northern part of Pilbailey Hill and the Wanda Wanda Creek area were mapped in some detail.

This text is prepared by the author (1) from his own notes and maps; (2) from theses prepared by four of his associates (Braybrooke and Middleton, 1964; Doepel, 1965; Muhling, 1965).

Physiography

The area lies in Jutson's "salinaland" (1934, p. 32) and there are three distinct erosion levels represented.

> *Residual Hill Features*—standing out as rocky ridges, which display bouldery outcrop and stand above the general level of the surrounding plain. These, the "inselbergs" of Jutson, are mainly formed of resistant meta-igneous basic and ultrabasic rocks ("greenstones").
>
> *Lateritised Plain*—the "old plateau" surface.
>
> *Lake Basins*—scooped out by erosion subsequent to the formation of the lateritised plain and bordered on the west by fresh rock outcrop in the form of low cliffs; their eastern shores are formed of kopai (gypsum) dunes which obscure the bedrock. The origin of these lake basins is debatable but it is quite obvious, viewing them from the air, that they represent a former drainage system now degraded to a branching system of discontinuous lakes.

Residual Hills in this area are those of Red Hill, Yilmia, Pilbailey Hill, the hill near the mouth of Wanda Wanda Creek and the hill of serpentinite which forms the highest feature of the Lefroy Peninsula. The lateritised surface, which forms the inland country elsewhere, does not seem to be a flat bevel, its level varying slightly up and down. It produces low lying areas of extremely poor exposure. The laterite is superimposed on a mottled zone which in turn passes down to kaolinised Precambrian rocks. The kaolinised sediments commonly show "Liesegang Ring" structures.

Rainfall is low (<10 inches per year) and temperatures range from >100°F during the long summer to <40°F during the cold, bleak, dry winter. The rain comes mainly in storms which sweep inland from the north-west coast at the end of cyclonic depression activity up there, during the summer months.

Surface coverings of siliceous hardpan, kunkar, surface limestone, magnesite and opal are common.

The vegetation is mainly of mulga, acacia, eucalypt, sandalwood and kurrajong on the metasediments; blue bush, salt bush and salmon gums on the laterite areas; and thicker growth of eucalypt and acacia on the belts of basic meta-igneous rocks ("greenstones"). The area is characterised by a remarkable lack of grass, stony earth surfaces intervening between scattered clumps of bushes and trees.

General account of the geology

Stratigraphy. The Kalgoorlie area has long been known to geologists on account of gold mineralisation at Kalgoorlie (in the Golden Mile) and Coolgardie, in the north, and Norseman in the south. This area lies between these mining fields and displays a wealth of metamorphosed sedimentary rocks. Early geologists tended to discount the presence of such metasediments, regarding the "greenstones" correctly as metabasic igneous rocks and much of the "whitestones" incorrectly as sheared porphyries or porphyrites. Some of the maps of fifty years covering part of the Lake Lefroy area show no metasediments at all. The extent of the metasediments in this particular area is correctly shown by Sofoulis and Bock (1962) and Sofoulis (1965), geologists who have carried out a regional survey, though without embarking on any differentiation of the metasediments as attempted here. The general geology of the belt of ancient rocks situated between immense bodies of almost equally ancient granite is well summarised by Prider (1961). The belt consists of abundant metasediments of geosynclinal origin (in the primary sense of Aubouin, 1966), locally isoclinally folded, displaying steep dips, and rather irregularly metamorphosed, though in general displaying *green-schist facies* assemblages. The regional sequence of events may be summarised:—geosynclinal sedimentation; ophiolite intrusion and extrusion; folding and metamorphism; granite* and albite-quartz porphyry* invasion (accompanied by porphyroid metasomatism of rudites?), late basic dyke intrusion on east-west fractures during a post-metamorphic period of tension. Some acid volcanics are present—but to what extent they are represented is debatable. The metamorphism has been dated as about 2,700 m.y. ago, the granite intrusion about 2,600 m.y. and the late dyke phase 2,420 m.y. ago (rubidium-strontium method, unpublished thesis, Turek, A., 1966).

It is now apparent from field and age-dating evidence that the granites bordering the belt represent later invasions of the ancient metamorphic rocks not a primitive Archaean basement beneath the sediments. Granite boulders in the conglomerates do, however, indicate a previous granite intrusion or granitisation episode and presumably a previous orogenic cycle.

The only later formations represented are the Plantagenet (Eocene) marine sediments, forming a very thin and sporadic sedimentary cover, and composed mainly of spongolite.

The area represents a continuation southwards of the sequence between Kalgoorlie and Coolgardie (Fig. 1), for which a stratigraphic sequence has long been accepted (covering the eastern half of the section):

* Much of the porphyries and at least some of the granite rocks experienced at least the last stages of tectonic deformation, associated with the orogeny; many of the porphyry bodies appear to be pre-orogenic.

Kurrawang Conglomerates

locally present (Yindarigooda (White Flag) Beds)

Black Flag Beds

Kalgoorlie Greenstones:
- Paringa Basalt*
- Golden Mile Dolerite*
- Williamstown Dolerite*
- Kapai Slate*
- Hannans Lake Serpentinite*

(Woodall, 1965)

The names marked with an asterisk are satisfactory for a mining area stratigraphy of extreme economic importance but local significance. It is, however, questionable whether on a regional scale it is not preferable to name the internal subdivisions of the metabasites and ultrabasic rocks of the "greenstone" (ophiolite) beds informally. The belts change character rapidly along the strike, and such a stratigraphy is likely to have no extension outside the Golden Mile for which it was very rightly erected. They include ultrabasic rocks which are certainly intrusive, and basic sills; these intrusions may transgress, change character, or disappear along the strike, and are obviously better named informally in the present work, only individual "greenstone" (ophiolite) belts being given a name. It is evident as a result of recent work extending into the lower part of the sequence that some sequences predominantly composed of pillowed metabasalts will have to be given formal status as "Beds", but it is still maintained that attempts to extend the complex internal stratigraphy of the ophiolite belts for any distance along the strike cannot lead to anything but confusion. The older names given to the various stratigraphic units in the Kalgoorlie area are not extended to this area, though in Table 1, the probable correlatives and the general relationship of the Lefroy Succession to the Kalgoorlie Succession are shown.

Glikson, (1968) has produced a stratigraphic sequence for the rocks of the Kalgoorlie System outcropping in the Mungari-Kurrawang area, to the north of the area considered here, and to the west of the Kalgoorlie area. His sequence from Coolgardie to Kurrawang is:

Sedimentary units	*Igneous units*
Kurrawang Beds	
Black Flag Metasediments	
	—(Red Lake Ophiolites)
Brown Lake Metasediments	
	—(Mt Robinson Ophiolites)
Gunga Meta-argillites	
	—(Coolgardie Ophiolites)

The probable correlation between the rocks of the Lefroy area and this sequence is also given in Table 1.

As is seen from a study of Table 1, and figures 2, 3, 4 and 5 (together with the accompanying sectional diagrams), the stratigraphic sequence has been divided into seven units, four of which are exposed to the west of the Yilmia Dislocation and three to the east of the dislocation. It is believed that the three units to the east of the dislocation are equivalent to units 2 and the lower part of unit 3 to the west of the dislocation, the sequence facing in opposing directions on either side of the dislocation, the structure being a broken synclinorium and the dislocation being a fault with considerable sinistral transcurrent component, throwing down to the east

The stratigraphy given here represents a revision of the sequence given in a previous summary (McCall *et al*, 1967), before the likely nature of the Yilmia Dislocation was fully understood. It had been customary amongst geologists working in this area to regard the Kurrawang Conglomerates (Glikson 1968) as equivelent to the conglomerates of the Merougil Beds further south, and many mining company maps show them in virtual strike continuity. However, more recent detailed maps produced by mining company geologists suggest that such a correlation is untenable. The Abattoir Line, a complex ophiolite belt including sills and serpentinite, trends north-east to south-west (Fig. 5) and continues southwards to join up with the Cave Rocks Ophiolite Belt, which appears to be truncated by the Yilmia Dislocation to the south of Cave Rocks (Fig. 2). The Abattoir Line Ophiolite and the enclosing dominantly pelitic metasediments separate the Kurrawang Beds from the Merougil Beds. It is clear that the Merougil Beds form a very thickened sequence, part of the west facing limb of the southern continuation of the Kurrawang Syncline, but are much lower in the sequence than the Kurrawang Beds, being separated from them by the Abattoir Line Ophiolite Belt and the enclosing metasediments. This interpretation allows correlation of the Merougil Beds with the rather thinner sequence of conglomerate beds of strikingly similar character on the western limb of the syncline, the Mandilla Beds, outcropping on the shore of Lake Lefroy, north of Widgiemooltha: and the Wanda Wanda Beds to be equated with the Cave Rocks Beds, though, clearly, the equivalent sequence to the Wanda Wanda Beds and their equivalents to the north, the Black Flag, Brown Lake and Gunga Beds of Glikson (1968), are significantly thinned on the eastern limb. The Yilmia Ophiolite Belt thus becomes stratigraphically equivalent to the Abattoir Line Ophiolite Belt. The Merougil Beds wedge out northwards against the eastern of the two dislocations, to the west of the Kambalda Ophiolite Belt[1].

The stratigraphy given is based on abundant facing evidence—pillow facings, cross-bedding, graded bedding, soft rock deformation structures and internal differentiation patterns in layered sills. The beds are for the most part

[1] This dislocation, evidence for the existence of which is given by Braybrooke and Middleton, 1964, may well continue northwards to join up with the Boulder Fault, which separates the Mt Hunt Ophiolites, presumed to be stratigraphically equivalent to them, from the Kalgoorlie-Kambalda Ophiolites. The sense of the displacement on this fault is not fully established, but the downthrow appears to be towards the west.

TABLE 1

Table 1.—Probable correlation between the rocks of the Lefroy area, the Kalgoorlie Sequence and the Mungari-Kurrawang Sequence.

				CORRELATION WITH THE KALGOORLIE SEQUENCE Kurrawang Conglomerates (not represented in this area)	CORRELATION WITH THE MUNGARI KURRAWANG SEQUENCE (Glikson, 1968)	OTHER LIKELY CORRELATIONS
7. CAVE ROCKS BEDS	c. 200' only limited outcrop	Metapelites† Metasandstones	CAVE ROCKS OPHIOLITE BELT	ABBATOIR LINE OPHIOLITE BELT AND ENCLOSING DOMINANTLY PELITIC SEDTS	RED LAKE OPHIOLITES BLACK FLAG BEDS	YILMIA MAIN OPHIOLITE BELT WANDA WANDA BEDS
6. MEROUGIL BEDS	16,000'	Metasandstones* Metaconglomerates* (polymictic) Metasiltstones		cut out by dislocation ?	Not represented ? Stratigraphic position between Gunga Meta-argillites and Coolgardie Ophiolites	MANDILLA BEDS
Possible gap or overlap						
5. TRIANGLE ISLAND BEDS	2,500'	Metasandstones* Metaconglomerates* (polymictic) Metasiltstones		cut out by dislocation	Not represented ? Stratigraphic position between Gunga Meta-argillites and Coolgardie Ophiolites	MANDILLA BEDS
YILMIA DISLOCATION						
4. LAKE DAM BEDS	300'	Sandstones* (undeformed clastic texture) Metasandstones* Chert or quartz fragment breccias* Metasiltstones				
3. WANDA WANDA BEDS	7,500'	Metasiltstones Metapelites† Metasandstones* Metaconglomerates* (polymictic) (quartz grits and actinolitic metasediments)	YILMIA MAIN OPHIOLITE BELT YILMIA WESTERN OPHIOLITE BELT	BLACK FLAG BEDS	BLACK FLAG BEDS BROWN LAKE BEDS GUNGA META-ARGILLITES RED LAKE OPHIOLITES MT. ROBINSON OPHIOLITES	CAVE ROCKS BEDS
2. MANDILLA BEDS	5,000'	Metasandstones* Metaconglomerates* (polymictic) Metasiltstones (actinolitic metasediments)	VESICULAR OPHIOLITE BELT			MEROUGIL AND TRIANGLE ISLAND BEDS
1. CAUSEWAY BEDS	7,500'	Metapelites† Metasiltstones Metasandstones* Metaconglomerates* (polymictic)	TOWN DAM OPHIOLITE BELT‡ (SPARGOVILLE OPHIOLITE BELT)		COOLGARDIE OPHIOLITES ? (near top of succession) and associated metasediments	KAMBALDA OPHIOLITES ? WOOLGANYER GROUP ? OF NORSEMAN (Bekker, 1963)
Bottom of sequence so far Mapped		Abundant actinolitic, tremolitic and hornblendic metasediments				

* Rocks of *metagreywacke* character or metaconglomerates with greywacke matrix.

† The term *metapelite* denotes metasediments finer than metasiltstones—strictly speaking "fine metapelites" (McCall & Dunbar, 1967): Glikson (1968) refers to these as "meta-argillites", but there are objections to this term.

‡ The Spargoville Ophiolite Belt is stratigraphically below the level of the lowest members of the Causeway Beds mapped at Widgiemooltha. It is believed to be in continuity with the Widgiemooltha Ophiolite Belt, just west of the township. The stratigraphy is only intelligible if it is accepted that there is a very drastic lateral thinning out northwards from Widgiemooltha, of tectonic or sedimentational origin (or both). The Causeway and Mandilla Beds thin out to the north: shearing increases and coarse clastic sediments become less evident. Similarly the equivalent formation to the Wanda Wanda Beds, containing the Abattoir Line-Cave Rocks Ophiolite Belt east of the Yilmia Dislocation appear to be attenuated.

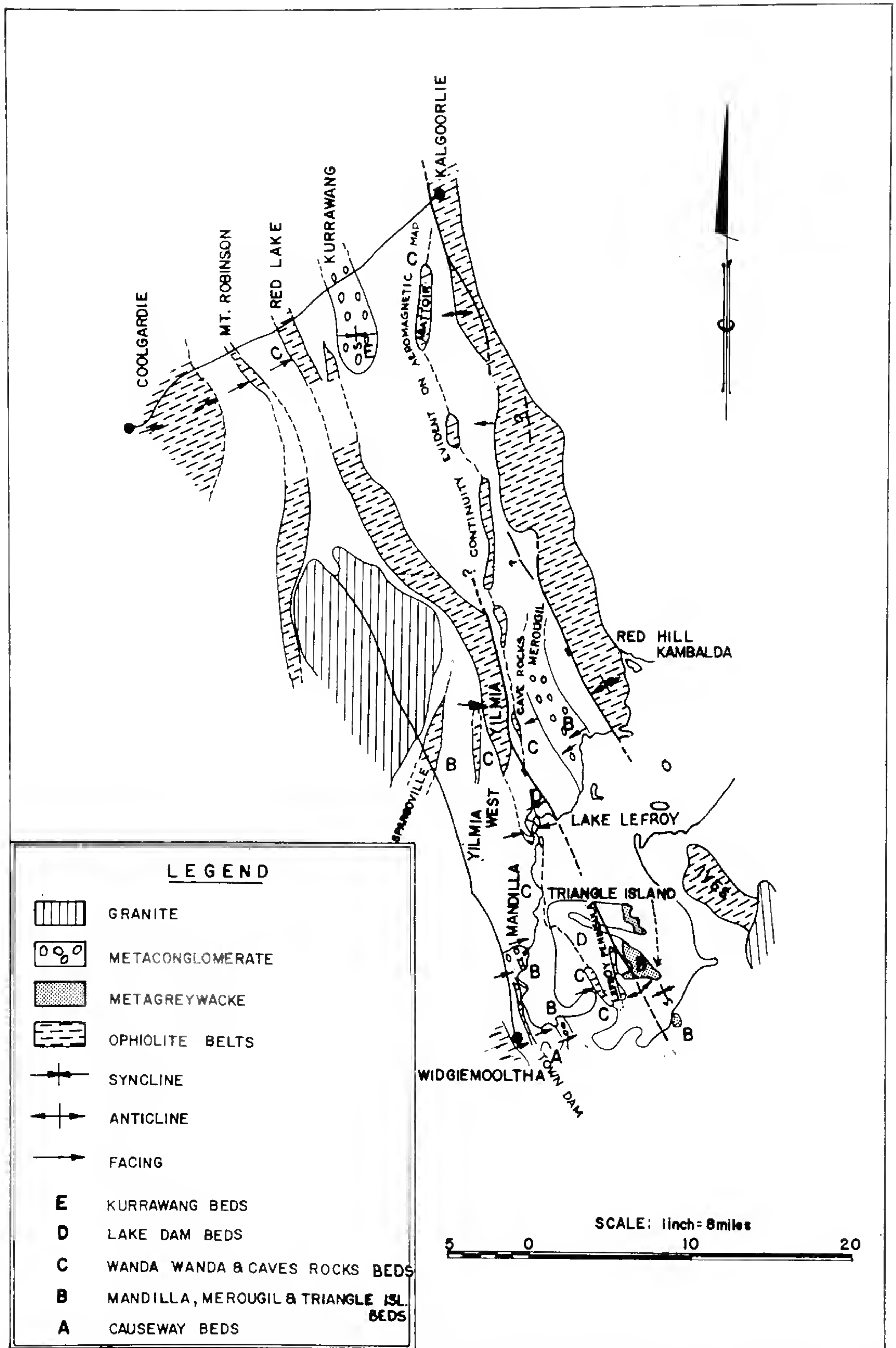

Figure 5.—Line diagram showing the possible correlation between the succession and structure of the area with with the formations situated to the north.

vertically disposed, but on the Lefroy Peninsula the keel of the gently north-plunging syncline is exposed in the outcrops of the Triangle Island Beds, which are taken to represent *either* their lateral equivalents or the lower part of that sequence, not exposed in the main outcrop near Merougil Creek because of truncation by the eastern of the two dislocations. The later explanation is preferred, and the stratigraphic table (Table 1) is drawn up in accordance with that preference.

The correlatives of the Lake Dam Beds, in which undeformed greywackes and sedimentary breccias composed of chert-like fragments are well developed, might well be found between the Abattoir Line Ophiolite and the base of the Kurrawang Conglomerates, in the eastern limb of the Kurrawang Syncline. It is noteworthy that the ophiolites of the Kambalda Belt are invaded by a number of small granite bodies with a marginal and outlying development of a porphyry phase. The conclusion was drawn by O'Beirne (1968) that these rocks suffered at least the terminal stages of deformation and metamorphism. Similar rocks are a feature of the ophiolites of the belt running through to the west of Widgiemooltha, especially near Dordie Rocks, and one may well enquire whether these intrusions do not have some indirect relationship to the concentration of nickeliferous sulphides—even though these are reportedly "post-ore?". Probably, there is evidence in the Kambalda Mines which would resolve this question.

The conclusion is drawn that the Kambalda Ophiolites and those to the west of Widgiemooltha are, like those at Coolgardie, near the base of the succession so far mapped. There is certainly some validity in the concept of an "ophiolite group", but the term is perhaps misleading for ophiolites occur at many levels in the stratigraphic succession. Preliminary mapping between Widgiemooltha and Norseman suggests that the ophiolites of the belt which develops in the Causeway Beds just above the Town Dam Ophiolite Belt immediately south of the area may be equivalent to the Desirable Pillow Lavas of the Norseman succession (Bekker, 1963), and it appears that all the thick Norseman sequence beneath this level is stratigraphically lower than the entire sequence given here.

Structure. It is apparent from the sections that the overall structure is a large scale synclinorium with the median zone complicated by two dislocations. Two complementary anticlinal structures border the synclinorium, one to the west of Widgiemooltha and the other passing through Kambalda. The metamorphic rocks have a north-north-westerly regional trend, and wedge out against a north-south trending granite contact, which indicates the intrusive nature of the granite, to the west of the area mapped.

No evidence of the interference fold pattern recognised by Horwitz and Sofoulis (1965) has yet been found within the limited area mapped. Lineation plunges are mostly north-north-westwards and gently inclined, though some moderately steep plunges are recorded, as well as some gentle to moderately steep southward plunges. In one outcrop near Widgiemooltha steep and westwards plunging small scale folds of isoclinal style were noted only inches away from a set of gently north-north-westward plunging lineations.

Some distance to the north of Widgiemooltha steep westerly plunges were again recognised, in crenulations within a jasper bar. These aberrant lineations certainly testify to cross folding in the area, of some sort, but there seems to be no evidence that it is not of simultaneous type, and the fold geometry does not seem to exactly match that deduced by Horwitz and Sofoulis (1965).

The thick sequence of the Merougil Beds has a homoclinal structure, there being no significant internal flexures of small scale in the thousands of feet thickness exposed. The thickness of this sequence could be overestimated for the upper and major part of the thickness given in Table I is only poorly exposed, and some of it could be equivalent to the lower part of the Wanda Wanda Beds.

In general, it seems that complex flexures, mainly isoclinal, though undoubtedly present in the sequence studied, are mostly localised within incompetent pelitic metasediment sequences and are second and third order flexures superimposed on a system of first order major flexures which can only be detected by facing measurements, and have wave lengths of tens of miles. Thus, while it has been suggested that facing indications are valueless in a sequence displaying such complex flexures which produce repetitions of the stratigraphic sequence, the mapping has shown that there is a consistent facing direction maintained over many miles across the strike, and that the general pattern of the first order folds does emerge from recording these facing indications, in spite of localised reversals which can be related to second and third order flexures.

No evidence has been found for major unconformity within the sequence, though there are minor discontinuities. While it is, admittedly, difficult to detect unconformities in such tectonically smoothed-out sequences and to be sure of the significance of those that are recognised, it seems to be a fact of critical significance that the sedimentary rocks of the Causeway Beds include polymictic conglomerate members that are lithologically very similar to the conglomerates of the uppermost beds of all, the Kurrawang Conglomerates. Though the amphibole content is rather higher in these lower conglomerates, and metapelites predominate over psammites and rudites in the sequence as a whole, the conglomeratic members contain porphyry, laminated metasediments, granites, quartzite and chert phenoclasts in that order of abundance, set in a highly altered greywacke matrix—a very similar phenoclast lithology to that of the Kurrawang Beds. The Kurrawang Conglomerates cannot be taken as indicative of

very special conditions pertaining at the end of the deposition in the geosyncline, only of a general tendency for rudites to predominate in place of pelites: and it does not seem acceptable to give them a molasse connotation.

The immense thickness of sediments and igneous rocks inferred (McCall *et al*, 1967) must be regarded with reserve: the Norseman sequence (Bekker 1963) of 85,000 feet is exaggerated, for some evidence is now available of east facings in the Mt Thirsty Group at the top, and this group is not now believed to represent a continuation of the west facing Norseman Homocline. Taking into account the thickness estimated in Table 1 and a conservative estimate of the Norseman sequence, together with the known thickness of the Kurrawang Beds, a total thickness of not far short of 100,000 feet of igneous rocks and sediments is inferred, and about 40,000 feet in the succession within the Causeway Bed-Kurrawang Beds sequence. This assumes that the Norseman sequence does come in largely *below* the Causeway Beds.

Admittedly, no complete section can be measured across the strike, and the figures obtained are the result of a synthesis of various sections—and thus no more than an approximation. The effects of tectonic and depositional thinning and igneous lensing cannot be assessed, though tectonic thinning will tend to reduce the original thickness. Yet it appears that at least down to the stratigraphic level of the base of the Causeway Beds, and very probably right down into the Norseman sequence to the lowest unit of all, the Penneshaw Beds, we are dealing with a single thick geosynclinal infilling, without *major* discontinuity, a sequence that, in spite of its thickness, may be reasonably regarded as one system. Horwitz and Sofoulis (1965) have suggested that there is a major unconformity between the upper and lower parts of this very thick sequence, but on the basis of limited evidence. Mapping recently carried out by the writer south of Widgiemooltha has indicated that the Causeway Beds extend southwards through the unnamed lake east of Dordie Rocks, and if there is any major unconformity it must be between there and the Norseman sequence beyond the northern Causeway, to the south of Hayes Hill.

The Acid Rocks. No rocks which have been unequivocally identified as acid volcanics have been recognised within the area studied. O'Beirne (1968) has stressed the difficulty in differentiating between surface volcanics and high level intrusions amongst the acid rocks loosely termed "porphyries" by local geologists. Reasonably detailed field and microscopic studies of the "porphyries" in this area have suggested that they are of two kinds—sheared acid porphyries of igneous origin and *porphyroids*, rocks which have the porcellainous appearance and same colour characteristics as the sheared igneous intrusions, but, though they may or may not display inset, larger crystals of albite or oligoclase, also display "ghost" relics of conglomerate pebbles. The pebbles are mostly extensively homogenised, but, in rare cases they are sufficiently unaltered to reveal the polymictic character of the conglomerate, from which they have apparently been derived by a form of metasomatism. Some porphyroids display ghost stratification, particularly near to the outer margin of the body, and the microtextures of the matrix of the porphyroid conglomerates commonly retain features indicating derivation from greywacke material, by a process of shearing, limited metasomatism and homogenisation. A limited number of chemical analyses of these porphyroid rocks by O'Beirne (1968) reveals variation patterns among the major elements that are unlike those of the "porphyries" of igneous origin: in general, it may be said that the variations are more marked and irregular, reflecting, apparently, compositional variations across the stratification of the original sediments. It must, however, be stressed that further geochemical studies are called for, especially in the form of very detailed studies of individual porphyroid occurrences. The porphyroid metasomatism certainly involves soda enrichment and O'Beirne suggests that it may, perhaps, best be regarded as a localised "metamorphic metasomatism" rather than a regional scale process. Some evidence of grouping of porphyroid occurrences close to granite occurrences, as at Widgiemooltha, does suggest the possibility that the process may be an outlying contact metasomatism related to the process of granite emplacement. The alternative is that it is a low grade metasomatism, mainly affecting rudites, and accompanying shearing and metamorphism, but not directly related to granite emplacement, in time and space. The porphyroids present a problem because, while it is quite easy to distinguish them from metamorphosed igneous porphyries in good lake shore outcrops, in poor inland outcrops they are quite indistinguishable from them.

No lava flow structures at all have been detected in the acid rocks, no vesicular structure and no occurrences of agglomerates or tuffs. The very thickness of some of the individual units seems to preclude surface volcanic origin, in some cases being in excess of half a mile without any variation in the nature of the rock exposed. It has been a local practice to refer to metagreywackes crammed with angular felspars as *crystal tuffs*, but the writer does not follow this usage—while it is, admittedly, difficult to account for such felspar-crammed wackes, we know far too little about the bare, vegetationless land surfaces of this ancient time, of the physical conditions pertaining to it (which possibly involved a reducing, anoxygenic atmosphere) and the processes of weathering and sedimentation thereon, to exclude derivation of such felspar detritus from other than volcanic sources.

The Ophiolites. The ophiolite belts are concordant and complex in internal structure, changing their character very rapidly along the strike, both as regards their total width and their internal stratigraphy: the internal sills seem to be impersistent along the strike and there is

some evidence of shallow, lensoid (funnel-shaped) form at Yilmia: and the degree of shearing and metamorphism is also variable along the strike. It is certain that much of the thinning of the belts (e.g. the Yilmia Main Ophiolite Belt which thins from two miles width to negligible width in about two miles strike distance) is due to shearing but this shearing may be located on the primary constrictions in the ophiolite belts. It seems quite certain that, considering the relationships between the pillowed and unpillowed, basic and ultrabasic metavolcanics on the one hand, and the coarsely crystallised rocks of the sill-form intrusions within the ophiolite belts on the other, a division into *older* and *younger* greenstones is unrealistic. The volcanics were characteristically erupted during periods of deposition of predominantly pelitic material, now represented by dark, fine, commonly carbonaceous metapelites, and one may reasonably attribute this association to eruption during a period of deepening of the basin of deposition. The sills are taken to represent penecontemporaneous eruptions of magma from the same stem, impeded on its passage to the surface by the damming effect of the early sea floor volcanic effusions, and so spread out laterally to fill favourable partings. There are rare, unmetamorphosed relics of felspyroxenites, norites, gabbros and dolerites. Their differentiation pattern, in the case of the best preserved examples—two sills in the Main Yilmia Ophiolite belt—is not unlike that of the Stillwater Intrusion, Montana (Hess, 1960). They are rare, unmetamorphosed relics of felspathic bronzitite cumulate. The serpentinites seem to represent something quite apart from the fine tremolite-chlorite ultrabasic rocks which commonly enclose them and seem, from chemical evidence, to have been picrite-basalts, though now converted to virtually felspar-free tremolite-actinolite/chlorite aggregates. Rather do the serpentinites appear to be metamorphosed ultrabasic intrusions, stemming from the same parental magma as the rocks of the differentiated sills. However, many of the serpentinites have the form of discrete ultrabasic bodies (of sill form ?) and are not simply the lower layers of gravity differentiated sills. There appear to be two distinct types of serpentinite occurrence:—

(a) *Discrete sills* (and cross-cutting intrusions?) This is the type represented at Yilmia and on the Lefroy Peninsula. It is believed to be the most favourable type of body for nickeliferous sulphide concentrations (mostly at the lower contact). They consist of serpentinite with marginal amphibolitic and chloritic rocks, but no associated gabbroic phases.

(b) *Lower layers of gravity differentiated sills.* While the peridotite basal phase layer of the Yilmia Sills is only slightly serpentinised, and there appears to be no representative of this type of serpentinite occurrences in this area, evidence from Ora Banda (Williams, 1967) and the Norseman Mission Sill (McCall, unpublished results) suggests that a substantial serpentinite body can be formed in the basal layers of a complex layered sill. Evidence from the Jimberlana Norite Intrusion at Mt. Norcott (Campbell, McCall and Tyrwhitt, unpublished manuscript, "The Jimberlana Norite, Western Australia—a smaller analogue of the Great Dyke of Rhodesia") shows that the serpentinisation is initially quite independent of regional metamorphism. Indications are that such serpentinite bodies show striking green staining by nickel, but are not such promising prospects for sulphide mineralisation as the discrete ultrabasic bodies.

The most difficult problem is the manner of separation of the ultrabasic melt that forms the discrete bodies of type (a) from the stem magma—presumably basaltic. It is noteworthy in respect of this unsolved problem that the Jimberlana Intrusion (Campbell, 1966; Campbell, McCall & Tyrwhitt, *op. cit.*), a large layered dyke-like body, reveals peridotite and picrite masses in the Ul layer (felspathic pyroxenite), and these appear to have formed small, discrete magmatic injections into the pyroxenite, with which they are unquestionably co-magmatic. It seems very unlikely that the discrete serpentinites represent injections of a primary ultrabasic magma, and are not derived from the common basaltic stem.

The sills of type (a) seem to be intruded slightly earlier than the layered sills, marking a slightly earlier phase in the penecontemporaneous sill emplacement process in each ophiolite belt (evidence from Yilmia). The associated tremolite-chlorite ultrabasics enveloping such discrete sills have the composition of picrites, but their origin remains obscure. Some fine-textured amphibolitic ultrabasics could prove to be regional metamorphic aureole derivatives of the serpentinites.

Chemical evidence and palimpsest textures leave no doubt that some type (a) serpentinites are derivatives of olivine-rich peridotites and dunites. Where intensely sheared they have been converted into dolomitic rocks, as near Bayley's Workings, but there is no reason to support, and every reason to discount, hypotheses of a genetic relationship to sedimentary dolomites.

Metabasite breccias have also been recognised, some on the Lefroy Peninsula being hyaloclastite breccias containing broken pillows. No other metabasite pyroclasts have been identified.

Metasediments. The metasediments are described in detail in accompanying papers dealing with the individual sub-areas. The only point that calls for comment here is the absence of banded iron formations and abundance in the lower part of the sequence of amphibolitic metasediments. In some of the Causeway Beds amphibole occurs as radiating prism clusters or "suns", and also as pods and discrete layers, which may show graded bedding, picked out by amphibole crystals. The origin of such amphibolitic metasediments has always been obscure.

Some metamorphic differentiation is suspected, for metasediments in the immediate vicinity of ophiolites tend to be amphibolitic. Yet this may be due rather to a concentration of material derived from the volcanics, though the fact that the amphibolite concentrations tend to occur at both upper and lower boundaries of the ophiolite belts favours the former explanation. Amphibolitic metasediments may also be due to chemical sedimentation, that is derived from metasediments with a significant CaMgFe content. Similarities between the textures and mineralogy of some of the metasediments in the Causeway Beds and amphibolitic metasediments in the Mt. Belches area (McCall and Dunbar, 1967) which are associated with quartz-magnetite-grunerite rocks, metamorphosed banded ironstones, suggest that much of the amphibolitic metasedimentary material is of primary sedimentary origin. Probably, metamorphic differentiation, chemical sedimentation, and the incorporation of volcanic detritus including basic tuff material, are all genetic factors in the widespread derivation of such metasediments. Whatever their origin, the amphibolitic metasediments are easily distinguished from the amphibolitic meta-igneous rocks.

Metamorphism. Metamorphism throughout the area studied has produced Upper Green Schist Facies Assemblages. There is much evidence of inhomogeneity and disequibrium, particularly in the basic rocks which show unmetamorphosed relics. The felspars in the metagreywackes may be albite or oligoclase, and the latter appears anomalous in the Green Schist Facies according to the definitions of Turner and Verhoogen (1960). Glikson (1968) has suggested that the rocks of this region sustained a low pressure, *Abukuma* type, metamorphism (Miyashiro, 1961). This suggestion seems reasonable in the light of the nature of the metabasalt assemblages which show a marked deficiency of epidote-chlorite associations, and also with the preservation of unmetamorphosed relics in the sills.

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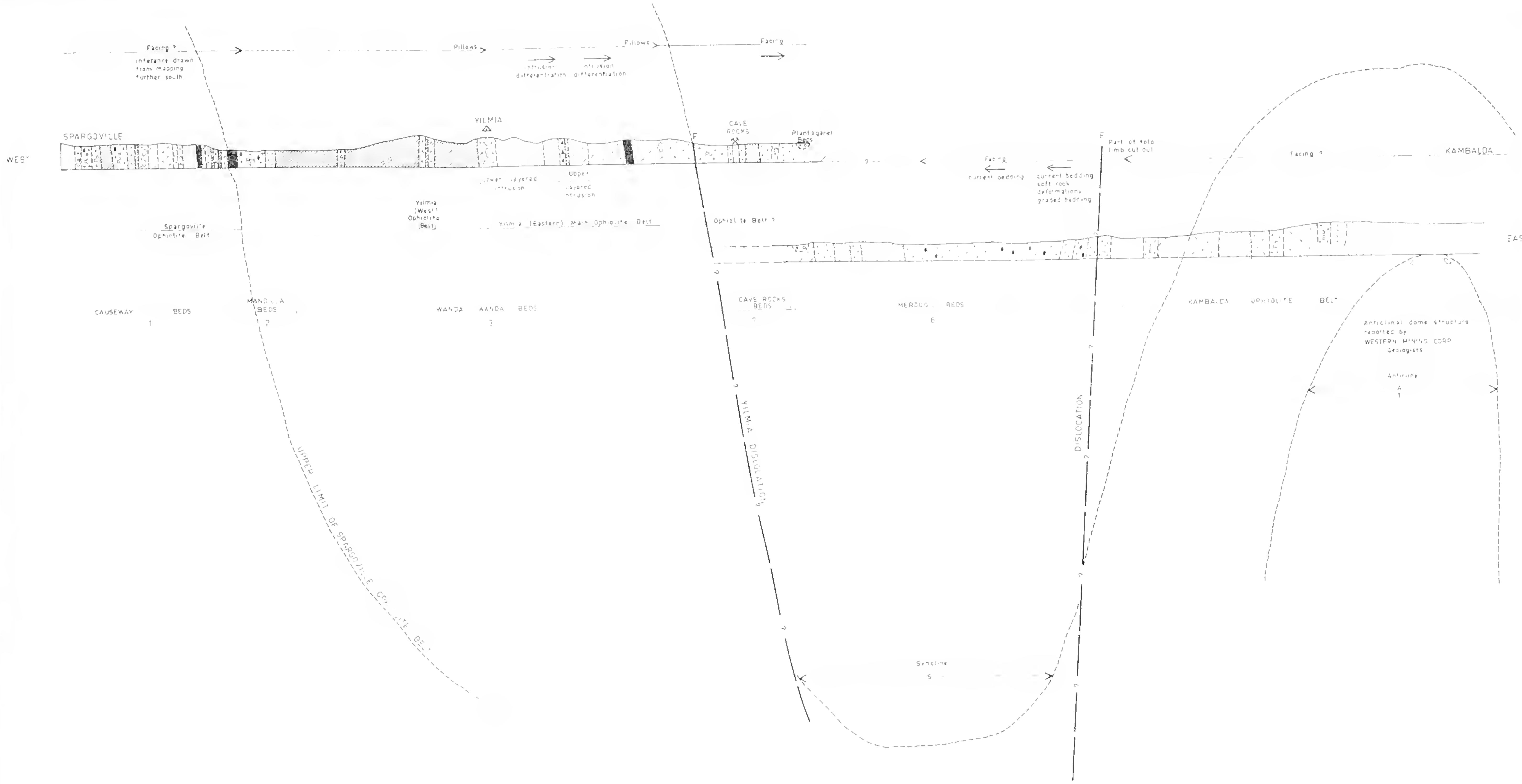
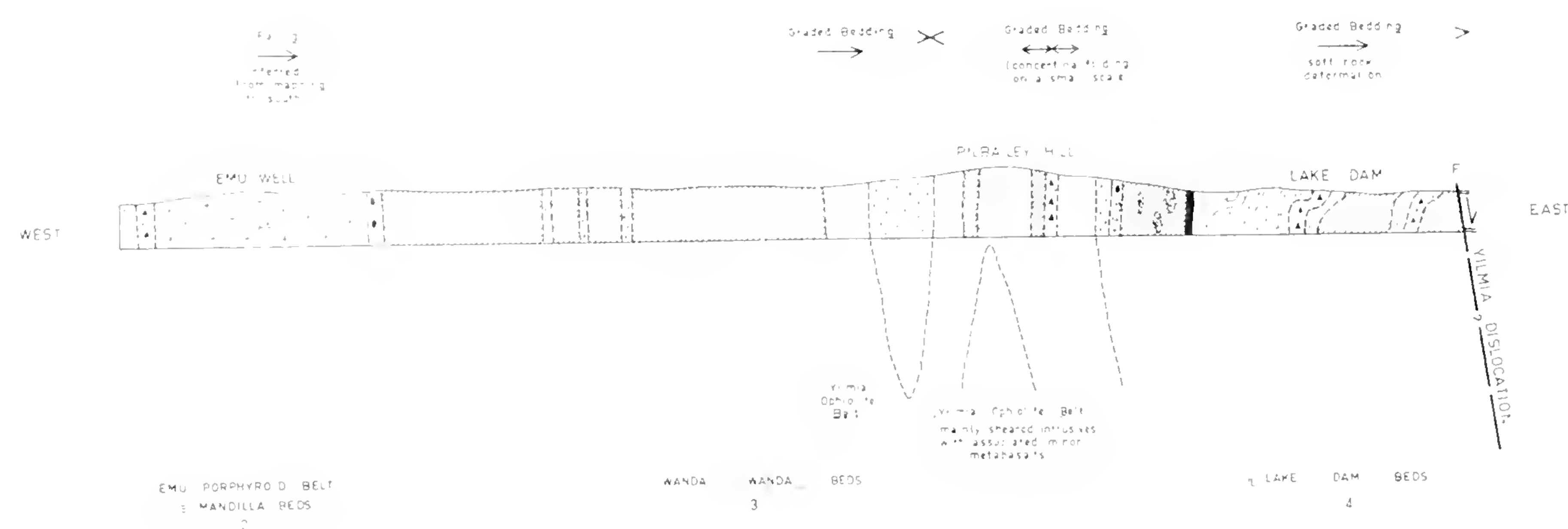
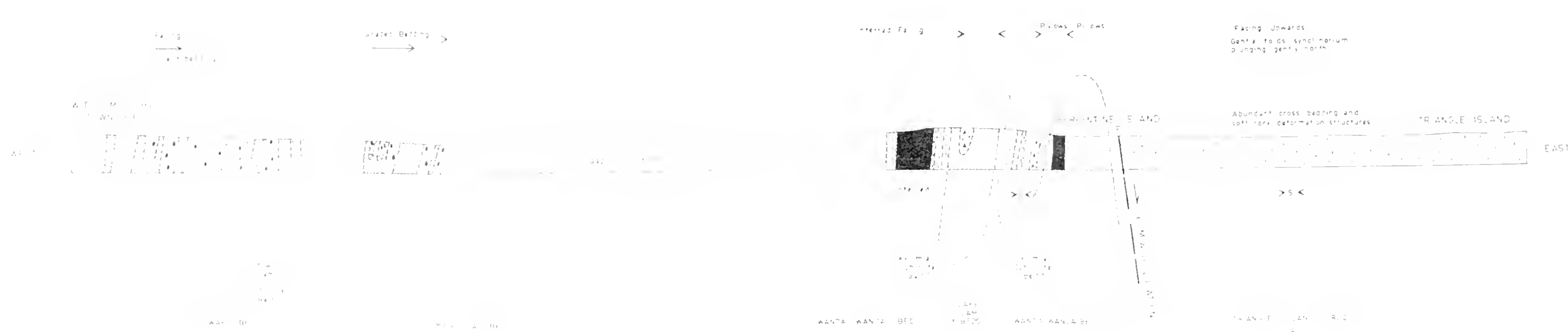


SECTION BETWEEN SPARGOVILLE AND KAMBALDA



SECTION BETWEEN EMU WELL AND LAKE DAM



SECTION BETWEEN WIDGIEMOOLTHA AND TRIANGLE ISLAND

GENERALISED SKETCH SECTIONS

SPARGOVILLE - KAMBALDA

EMU WELL - LAKE DAM

WIDGIEMOOLTHA - TRIANGLE ISLAND

EAST COOLGARDIE GOLDFIELD

WESTERN AUSTRALIA

SCALE Horizontal 0 20 40 60 chains

REFERENCE

RECENT
- Undifferentiated sand plain

EOCENE
- Spongolites, grits and capping laterite of Plantaganet Beds

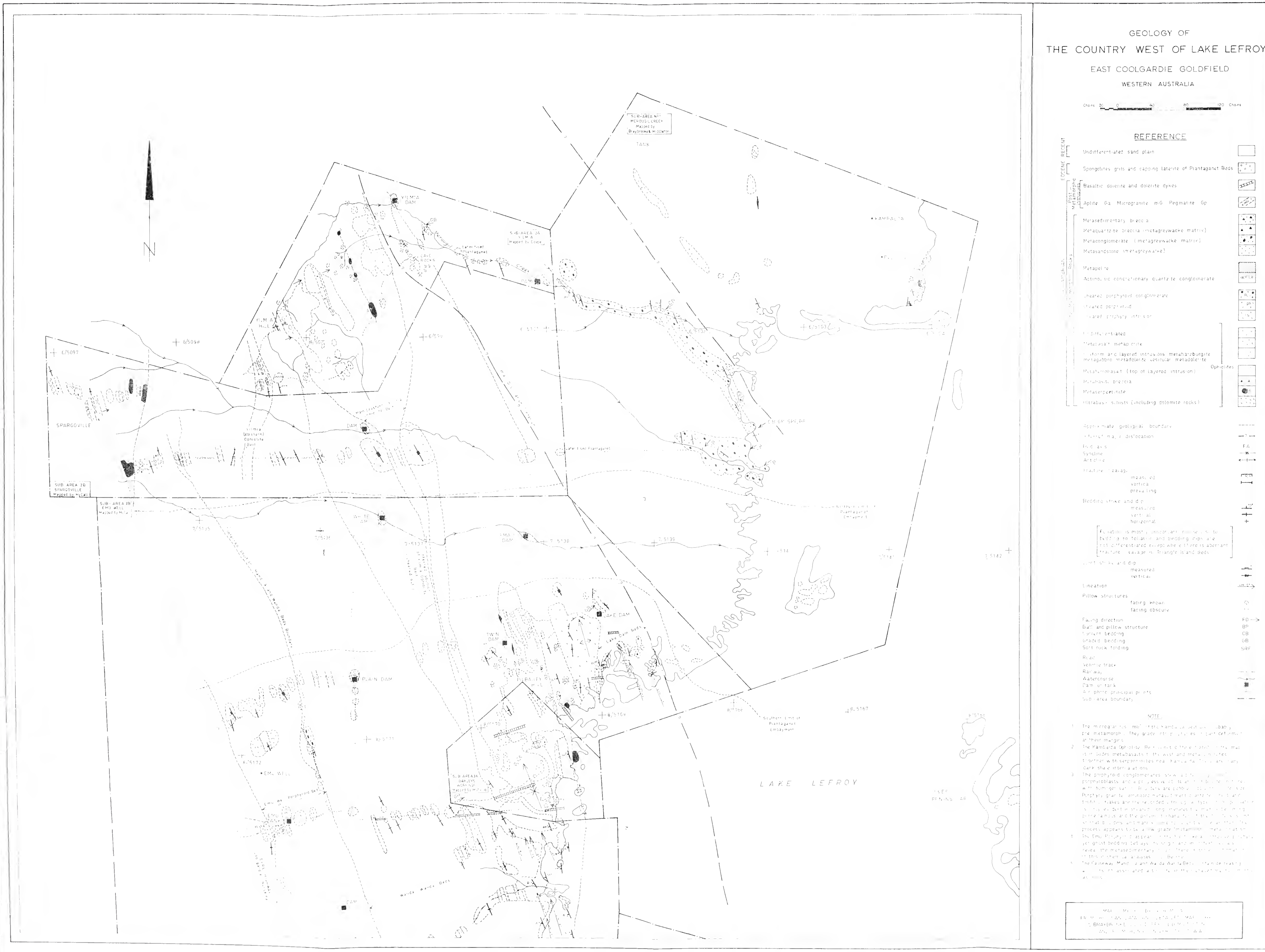
EARLY PRECAMBRIAN

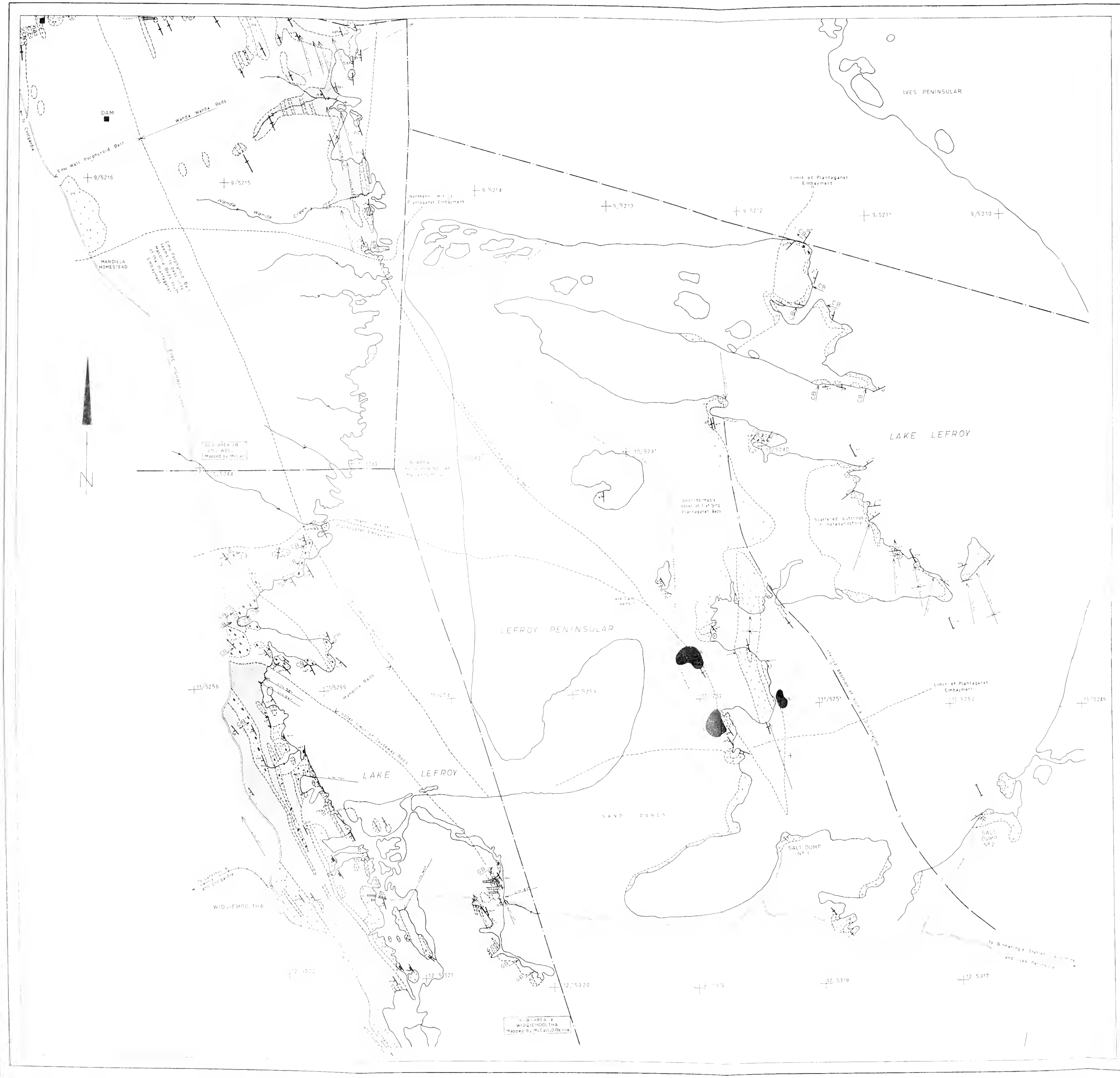
Post-Metamorphic Intrusives
- Basaltic dolerite and dolerite dykes
- Aplite Ga Microgranite mG Pegmatite Gp

Pre-Metamorphic Rocks
- Metasedimentary breccia
- Meta quartzite breccia (metagreywacke matrix)
- Metaconglomerate (metagreywacke matrix)
- Metasandstone (metagreywacke)
- Metapelite
- Actinolitic concretionary quartzite conglomerate
- Sheared porphyroid conglomerate
- Sheared porphyroid
- Sheared porphyry intrusion

Ophiolites
- Undifferentiated
- Metabasalt metapicrite
- Sillform and layered intrusions metaharzburgite metagabbro metadolerite vesicular metadolerite
- Metaferrobasalt (top of layered intrusion)
- Metabasite breccia
- Metaserpentinite
- Ultrabasic schists (including dolomite rocks)

- Approximate geological boundary
- Inferred major dislocation
- Syncline
- Anticline
- Fracture cleavage prevailing
- Pillow structure
  - facing known
  - facing obscure
- Facing direction


GEOLOGY OF
THE COUNTRY WEST OF LAKE LEFROY
EAST COOLGARDIE GOLDFIELD
WESTERN AUSTRALIA
Chains 20 0 40 80 120 Chains
REFERENCE
EOCENE
RECENT
Undifferentiated sand plain
Spongolites grits and capping laterite of Plantaganet Beds
Post-Metamorphic Intrusives
Basaltic dolerite and dolerite dykes
Aplite Ga Microgranite mG Pegmatite Gp
Metasedimentary breccia
Metaconglomerate (metagreywacke matrix)
Metapelite
Ophiolites
Ultrabasic schists (including dolomite rocks)
Syncline
Lineation
Pillow structures
facing known
facing obscure
Facing direction FD
Ball and pillow structure BP
Current bedding CB
Graded bedding GB
Soft rock folding SRF
Watercourse
NOTE
LAKE LEFROY
SPARGOVILLE
EMU WELL
PLAIN DAM
LAKE DAM
TWIN DAM
YILMIA DAM
KAMBALDA
N



GEOLOGY OF
THE COUNTRY WEST OF LAKE LEFROY
EAST COOLGARDIE GOLDFIELD
WESTERN AUSTRALIA

Chains 20 0 40 80 120 Chains

REFERENCE

RECENT
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EOCENE
- Spongolites, grits and capping laterite of Plantaganet Beds

EARLY PRECAMBRIAN

Post-Metamorphic Intrusives
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- Metaferrobasalt (top of layered intrusion)
- Metabasite breccia
- Metaserpentinite
- Ultrabasic schists (including dolomite rocks)

Approximate geological boundary
Inferred major dislocation
Fold axis FA
Syncline
Anticline
Fracture cleavage
- measured
- vertical
- prevailing

Bedding strike and dip
- measured
- vertical
- horizontal

Foliation is mostly concordant or closely so to bedding so foliation and bedding dips are not differentiated except where there is aberrant fracture cleavage in Triangle Island Beds

Joint strike and dip
- measured
- vertical

Lineation
Pillow structure
- facing known
- facing obscure

Facing direction FD
Ball and pillow structure BP
Current bedding CB
Graded bedding GB
Soft rock folding SRF

Road
Vehicle track
Railway
Watercourse
Dam or tank
Air photo principal point
Sub-area boundary

NOTES

1. The microgranites (mG) of the Kambalda belt are probably pre-metamorphic. They grade into porphyries in part deformed at their margins.
2. The Kambalda Ophiolite Belt is not differentiated on the map. It includes metabasalts to the west and metacumulates together with serpentinites near Kambalda. There are many dark shale intercalations.
3. The porphyroid conglomerates show albite (oligoclase) porphyroblasts and a progressive obliteration of boulder outlines with homogenisation. Boulders are pebble cobble or boulder size. Porphyry granite laminated metasediment quartzite chert and biotitic flakes are the recorded lithological types. Homogenisation is only evident in sheared conglomerates, the matrix becoming porcellainous and the polymict character of the boulders is lost so that boulders and matrix come to resemble one another. The process appears to be a low grade 'metamorphic metasomatism'.
4. The Emu Porphyroid appears in the field like an intrusive porphyry yet ghost bedding betrays its origin and microtextures also reveal the metasedimentary origin. There is some confirmation of this in chemical analyses (O Beirne).
5. The Causeway Mandilla and Wanda Wanda Beds contain decreasing amounts of associated actinolite in the metasediments (must as suns.)

MAP COMPILED BY G. H. McCALL
FROM HIS OWN DATA AND FROM DETAILED MAPS BY
J.C. BRAYBROOKE, J.G. DEEPEL, D.D. MIDDLETON
AND P.C. MUHLING, UNIVERSITY OF W.A.

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